ESSAYS ON UNCONVENTIONAL MONETARY POLICIES

by

Derin Aksit

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Abstract

This dissertation contains three essays on unconventional monetary policies.

Forward guidance during the zero lower bound period is typically modeled as news that alters the expected liftoff date of the policy rate, assuming that agents do not expect a policy rate hike in near future. In the first chapter, I empirically reject this assumption using U.S. high-frequency data and show that forward guidance affects the entire term structure of expected rates. Introducing this estimated forward guidance shock in a standard New Keynesian model substantially magnifies the "forward guidance puzzle". I show that allowing agents to update their macroeconomic expectations in the pessimistic direction following a forward guidance easing explains this larger puzzle *per se*, unlike the common approach of introducing a discount parameter due to a deviation from baseline assumptions. In addition, I find that the puzzle can also be explained by sticky information general equilibrium models.

Central bank communication could be interpreted in two ways, either as central bank's commitment to a future action, known as Odyssean guidance, or its forecast of future economic conditions, known as Delphic guidance. The empirical literature has identified the Delphic and Odyssean components of forward guidance policies. In the second chapter, I show that another unconventional policy tool, large-scale asset purchases, can also be empirically decomposed into Delphic and Odyssean components, and these two components have opposing impacts on macroeconomic expectations in the US along with other advanced and emerging market economies. Finally, I estimate the asset price responses to Delphic and Odyssean policies.

In the third chapter, I identify the Bank of England's forward guidance and quantitative easing surprises during the effective lower bound period in the UK. Then, I estimate asset price responses to these unconventional policies by local projections. I show that both surprises significantly move gilt yields and term premia on days of monetary policy announcements. However, their impact persists for only a few months. I further document that only forward guidance is effective in moving stock prices and their volatility. While both surprises influence the British pound, the impact of forward guidance persists for at least six months.

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Dedication

To my parents, Tijen Aksit and Necmi Aksit, for always believing in me...

To my lovely wife, Melis Atalar Aksit, for always bringing the best out of me...

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1.1 Introduction

At the August 2011 Federal Open Market Committee (FOMC) announcement, the Federal Reserve (Fed) communicated that it expects "exceptionally low levels for the federal funds rate at least through mid-2013". The Eurodollar futures rates immediately reacted, implying a 29 basis point drop in the expected 3-month rate as of June 2013. Standard New Keynesian (NK) models imply that rational agents raise their inflation expectations today following a decline in the expected future path of the policy rate. As the expected real rates drop, both consumption and production increase immediately.

Del Negro et al. (2015) show that the empirical response of output and inflation expectations to forward guidance (FG) announcements is much smaller than the one predicted by the standard NK models. They label this discrepancy the "forward guidance puzzle". An FG shock that lowers the expected 8-quarter-ahead nominal short rate by 25 basis points could raise production and inflation on impact by more than a few percentage points in these models. Empirically, the impact is much smaller and is not instantaneous. A growing literature attempts to understand in what ways these NK models are misspecified.

In this paper, I make two contributions to this line of literature. First, I show that much of the existing literature understates the magnitude of the misspecification. The usual method of modeling an FG shock is as an innovation in the 8-quarter-ahead nominal short rate. Hence, FG is widely modeled as a one-period extension to a zero lower bound (ZLB) period, the duration of which was already known by all agents. I document that, empirically, an FG shock that lowers the 8-quarter-ahead nominal short rate *also* lowers the expected short rates at all preceding quarterly horizons in the US during the ZLB period. The cumulative macroeconomic effects of these lower expected short rates are, in standard NK models, about two times larger (in terms of the instantaneous responses) than the macroeconomic effects produced by the usual FG modeling approach. Second, I evaluate which modifications to NK models are able to fit the empirical responses of macroeconomic variables to FG by running a "horse-race" among the best performing models from three different classes of models.

The common approach within this line of literature is to introduce a discount mechanism that governs the deviation from a baseline assumption. This mechanism is often summarized by a discount parameter in the NK Phillips curve and the dynamic IS curve that dampens the excessive response of an NK model. For example, Gabaix (2020) introduces a discount parameter due to bounded rationality, which is defined as the underestimation of the future deviations of macroeconomic variables from their steady states. I show that the degree of bounded rationality required to explain the FG puzzle is implausibly large. Since the bounded rationality framework of Gabaix (2020) is the best performing discount mechanism (in terms of its ability to dampen the excessive response implied by a standard NK model) among the most cited discount mechanisms proposed within this class of models, I argue that the approach of introducing a particular discount mechanism is not able to fully explain the FG puzzle.

An alternative modification to a standard NK model is to relax the standard assumption that FG only alters the future interest rate expectations without revealing any information about the state of the economy. Nakamura and Steinsson (2018) and Andrade et al. (2019) introduce a framework in which information about the state of the economy is revealed to agents through FG or agents infer the macroeconomic forecasts of the central bank through FG. This approach is motivated from the empirical finding that macroeconomic expectations could be adjusted in either direction depending on the magnitude of the two opposing implications of FG. In particular, an FG communication could either be interpreted as the central bank's commitment to a future action or its forecast of future macroeconomic conditions. I call the former channel Odyssean and the latter channel Delphic following Campbell et al. (2012). Motivated by this line of literature, I propose a framework in which agents infer what they think the central bank's macroeconomic expectations are[1] and show that a plausible probability of Delphic interpretation suffices to fully explain the FG puzzle.

[1]The standard assumption is that agents correctly interpret the announced interest rate path as Odyssean.

Another branch of the literature proposes to replace the sticky price assumption of the standard NK models with sticky information. In particular, Chung et al. (2014), Carlstrom et al. (2015), Kiley (2016) replace the NK Phillips Curve with the less forward-looking sticky information Phillips curve to explain, at least in part, the FG puzzle. In this paper, I show that the alternative approach of using a sticky information general equilibrium model could also be sufficient to fully explain the puzzle implied by an estimated FG shock.

Related Literature This paper is linked to a number of different lines of literature. Shortly after the Fed communications gained more importance with the ZLB, Laséen and Svensson (2011) helped establish a standard for introducing an FG shock in an NK model. They show that FG can be captured as future monetary policy shocks, i.e. shocks with non-zero time varying means, in a NK model. The most common way of introducing an FG shock is through a one-period drop in the policy rate in N quarters (e.g. Del Negro et al. (2015), Gabaix (2020), Chung et al. (2014), Gali (2018), McKay et al. (2016), Bundick and Smith (2020), Farhi and Werning (2019)). This approach assumes that the duration of the ZLB period is known with certainty by all agents before the announcement and forward guidance is a one-period extension to the ZLB period. I call this a "one-period FG shock" and show that it is not empirically plausible for the ZLB period in the US.[2]

Starting with Del Negro et al. (2015), a newly emerging line of literature proposes possible ways to address the FG puzzle. The common approach is to discount the NK Phillips

[2] The only two papers that use an FG shock which moves the entire term structure of interest rates that I am aware of are Nakamura and Steinsson (2018) and Campbell et al. (2019).

Curve (NKPC) and the dynamic IS curve in a standard NK model. Del Negro et al. (2015) propose introducing probability of dying through a perpetual youth framework as in Blanchard (1985) as a way of solving the FG puzzle. Alternatively, Gabaix (2020) introduces a discount parameter due to cognitive myopia. In this formulation, agents with cognitive myopia have bounded rationality (BR) and underestimate the deviations from a balanced growth path. McKay et al. (2016) introduce uninsurable income shocks and borrowing constraints in order to discount the response of consumption through precautionary savings. Angeletos and Lian (2018) remove common knowledge of relevant news to introduce higher order uncertainty.[3]

A smaller strand of literature is motivated by the opposing implications of FG on macroeconomic expectations (see e.g. Campbell et al. (2017)) and introduces a mechanism through which FG conveys information about the state of the economy.[4] Nakamura and Steinsson (2018) incorporate the information conveyed about the macroeconomic fundamentals as a change in the trajectory of the natural rate of interest proportional to that of the future policy rate. Therefore, the central bank not only impacts the path of the policy rate but also the path of the real interest rate that would prevail absent pricing frictions.[5]

[3]Other examples include: Hagedorn et al. (2019) who employ incomplete markets, Campbell et al. (2017) who introduce preferences for government bonds, Kaplan et al. (2018) who use ex-post heterogenous agents, Campbell and Weber (2018) who introduce imperfect credibility, and Farhi and Werning (2019) who employ BR and incomplete markets simultaneously.

[4]Bauer and Swanson (2020) recently proposed an argument which attributes these opposing implications to not controlling for macroeconomic news announcements. The second chapter of this dissertation shows that the Delphic components of FG and LSAP surprises remain very significant after controlling for macroeconomic news announcements.

[5]Although the authors do not discuss the implications for addressing the FG puzzle, I find that an implausibly large Delphic component (98%) is required to explain the larger FG puzzle.

In similar work, Andrade et al. (2019) model a negative structural shock which drags the economy into a liquidity trap in the spirit of Eggertsson and Woodford (2003). They model "date-based" FG as a commitment to stay at the ZLB for longer than the duration implied by the negative structural shock, in the presence of Delphic agents who believe there will be no additional accommodation at the end of the ZLB period. Hence, the nature of the FG experiment in their paper is different from the one proposed in this paper.[6]

A parallel line of literature proposes to employ sticky information models with inattentive firms as in Mankiw and Reis (2002) to mitigate the puzzle (see e.g. Chung et al. (2014), Carlstrom et al. (2015), Kiley (2016)). These models replace the forward-looking Phillips curve used in sticky price models. Since firms choose to update their information sets sporadically, the price level is mostly determined by the past expectations of today's optimal price rather than today's expectations of future optimal prices. Hence, news about the future has much milder effects.[7] I show that a sticky information model, in which consumers are also inattentive, can also explain the puzzle implied by an estimated FG shock.

The rest of the paper is organized as follows: Section 2 estimates an FG shock for the first ZLB period in the US and shows that using this estimated FG shock substantially magnifies the FG puzzle. Section 3 presents a baseline sticky price model, a BR framework,

[6]They assess the implications of committing to stay at the ZLB through "date-based" FG following a structural shock as in Eggertsson and Woodford (2003) instead of introducing FG as a future policy shock in the spirit of Laséen and Svensson (2011).

[7]Eggertsson and Garga (2019) highlight that sticky information models imply a smaller initial response than sticky price models in the presence of FG shocks. They further show that the sticky information framework does not perform better than the sticky price framework when a structural shock moves the policy rate to the ZLB.

a Delphic interpretation framework and a sticky information general equilibrium model. Section 4 describes the data and explains the estimation methodology. Section 5 discusses how well the described models can explain the larger FG puzzle. Section 6 concludes.

1.2 A Larger Forward Guidance Puzzle

1.2.1 Modeling a Forward Guidance Shock

An FG shock is an information shock about the future path of the policy rate. Thus, it is categorically different from a conventional monetary policy shock. While a conventional shock conveys information about the policy rate at $t = 0$, an FG shock conveys information about the next N periods. Due to the expectations hypothesis of the term structure of interest rates, a surprise that changes the interest rate expectations of the next N periods is equivalent to a sequence of future monetary policy shocks for the next N periods, assuming there is no change in term premia.

The red line in Figure 1 shows a widely used FG shock in the FG puzzle literature. Note that the interest rate expectations do not change for the next $N-1$ periods. This is due to the implicit assumption that market participants' ex-ante interest rate expectations for the next $N-1$ periods were 0. Hence, FG is captured as a one-period extension to a ZLB period, the length of which was common knowledge before the announcement.[8]

[8]Note that this "date-based" FG modeling is a practical but not realistic exercise in which the central bank announces the exact liftoff date. In the US, the Fed communicated the *minimum* expected length of the ZLB period in only three announcements: August 2011, January 2012 and September 2012.

Contrary to this simplifying assumption, the survey expectations of the short rates during the ZLB period in the US, as depicted in Figure 2, indicates that market participants did not expect the ZLB period to last very long. Using intraday futures data, I test the empirical plausibility of this simplifying assumption by estimating the high-frequency response of interest rate expectations for the next $N-1$ periods to an FG surprise that moves the Nth period expectations in the US during the ZLB period.

In order to test this, one needs to set a horizon over which the Fed's FG policies shape the interest rate expectations during the ZLB period. I set $N = 8$ due to the widely accepted argument that Fed's FG policy operates through a roughly two-year horizon during the ZLB period[9] (e.g. Swanson and Williams (2014), Hanson and Stein (2015), Gertler and Karadi (2015)). Clearly, one also needs to identify an empirical FG surprise.

1.2.2 Identification of an Empirical FG Surprise

I identify the FG and LSAP surprises following a similar methodology as in Rogers et al. (2018). I characterize the 120-minute changes (from 15 minutes before the announcement to 1 hour and 45 minutes after the announcement) in the 8th Eurodollar futures rates, i.e. the market expectations of what the short rates in the US is going to be roughly in two years, as the FG surprise.[10] I assume that term premia do not change over this small in-

[9]One could argue for a higher horizon for the ZLB period (e.g. Campbell et al. (2019) uses N=10). Setting $N > 8$ makes the conclusions of this paper stronger.

[10]The choice of Eurodollar futures to capture the interest rate expectations is due to the liquidity of these assets. Their high-frequency response to FOMC announcements within a 120-minute window is highly volatile. One might argue that the interest rate expectations in the US are better captured by the OIS rates.

terval following the literature[11] (e.g. Piazzesi and Swanson (2008), Cochrane and Piazzesi (2005), Evans and Marshall (1998)).

As noted by Swanson (2020), this surprise is very highly correlated with the FG factor obtained through rotating the first two principle components of asset price movements as in Gürkaynak et al. (2005). Note that the Fed funds futures rate, i.e. the market expectations of what the Fed funds rate will be at the end of the current or next month, and its surprises were practically zero during the ZLB period.

The asset price movements around FOMC announcements at the ZLB period can be explained by the two principal components of the changes in interest rate expectations at different horizons as shown in Swanson (2020). These principal components can be rotated to have the structural interpretation of FG and LSAP surprises. Following Rogers et al. (2018), I identify LSAP surprises by regressing the 120-minute change in the 10-year Treasury yields around FOMC announcements on the FG surprise. I characterize the residuals of this regression as the LSAP surprise. Thus, the high-frequency response of the high end of the yield curve is explained by the combination of FG and LSAP surprises by construction. Figure 3 shows the identified empirical FG and LSAP surprises during the ZLB period.

However, the OIS futures are less volatile. In order to control for the difference between the interest rate implied by Eurodollar futures (the LIBOR rate) and the OIS rate, I check the daily response of the LIBOR-OIS spread to an FG surprise and find no economic significance. The spread moves a basis point in response to an FG surprise that moves the 8-quarter-ahead interest rate expectations by 25 basis points.

[11] I also find that the term premium component of the two year rates do not significantly move at the daily frequency around FOMC announcements during the ZLB period.

1.2.3 Response of Interest Rate Expectations to an FG Surprise

I test whether the interest rate expectations of the next 7 quarters respond significantly to an FG surprise. Equation (1) shows the regression employed to measure the high-frequency response of the first 8 Eurodollar futures rates to an FG surprise which moves the 2-year interest rate expectations (8th Eurodollar futures rate) by 25 basis points (bps).

$$\Delta ED_t^i = \beta_0^i + \beta_{FG}^i FG_t + \varepsilon_t^i \tag{1}$$

where ΔED is the 120-minute change in the ith Eurodollar futures rate, $i \in \{1,2,..,8\}$, around each FOMC meeting. FG is the FG surprise. $t \in T$ where T=55, the number of FOMC announcements during the ZLB period. I plot the results of this regression (after normalizing for an easing FG surprise) for $i \in \{1,2,..,8\}$ in Figure 4. The estimated coefficients are the percentage point (pp) changes in the interest rate expectations in response to an FG surprise that moves the 8-quarter-ahead interest rate expectations by 25 bps.

1.2.4 Using Empirics to Model an FG Shock

Figure 4 shows that the high-frequency movement of the first 7 Eurodollar futures rates in response to an FG surprise that moves the 8th Eurodollar futures rate by 25 bps around FOMC announcements during the ZLB are all statistically significant. When the Fed announces that interest rates will remain at the ZLB for longer than market participants had expected, interest rate expectations of the horizons the Fed referred to move closer to 0 after the announcement. Thus, Figure 4 implies that on average the market participants had an ex-ante expectation of a strictly positive future interest rate path at any quarterly horizon during the ZLB period.[12]

The black line in Figure 1 captures this collapse in the interest rate expectations in response to an FG shock that lowers the 8-quarter-ahead interest rate expectations by 25 bps. I call this black line an "estimated FG shock" and the red line a "one-period FG shock". An estimated FG shock that lowers 8-quarter-ahead interest rate expectations by 25 bps is equivalent in magnitude (in terms of the implied impulse responses at time 0) to a one-period FG shock that lowers the 8-quarter-ahead interest rate expectations by about 60 bps. Hence, the estimated FG shock is about *two times more powerful* than the one-period FG shock. The reason why it is not four times more powerful (note that the cumulative interest rate cut in the estimated FG shock is about four times larger than the one in the one-period FG shock) is that the near future policy shocks are less powerful in standard NK models.

Note that the size of the FG shock in this policy exercise is plausible for the ZLB period. The blue line in Figure 3 depicts the pp change in the 2-year interest rate expectations. The March 2009 announcement, which initiated QE1, communicated that the FOMC expects to

[12]This result holds for different sub-samples of the ZLB period. It is also consistent with the survey evidence in which investors expected the liftoff from the ZLB to be roughly in 2 quarters before 2012 and increased their expectations by a few quarters afterwards.

keep the Fed funds rate between 0 and 25 bps for "an extended period". This decreased the 2-year interest rate expectations by 21 bps. Similarly, the August 2011 announcement of the FOMC, which communicated that the FOMC expects to keep the Fed funds rate between 0 and 25 bps "at least through mid-2013", lowered the 2-year interest rate expectations by 29 bps.

1.2.5 A Larger FG Puzzle to Address

The implication of this empirical finding is crucial for structural modeling since addressing the FG puzzle gets more difficult in the presence of a sequence of future policy shocks rather than a single future policy shock. Since the estimated FG shock is about two times more powerful in a standard NK model, the FG puzzle is much more difficult to address. Hence, a natural question to ask is whether the proposed solutions in the FG puzzle literature are able to address the puzzle implied by an estimated FG shock. In order to address this question, I run a "horse-race" among three models from different branches of the literature: i) introducing a discount mechanism in a sticky price model, ii) allowing FG to reveal information about the state of the economy in a sticky price model and iii) switching to sticky information as the main source of nominal rigidity. I use the best performing model for addressing the FG puzzle in each branch: i) a sticky price model with BR as proposed by Gabaix (2020), ii) a sticky price model with Delphic interpretation as proposed in this paper and iii) a sticky information general equilibrium model as in Reis (2009).

1.3 Bounded Rationality, Delphic Interpretation and Sticky Information

First, I describe a standard sticky price model in which the FG puzzle emerges. Then, I present the BR framework proposed by Gabaix (2020) to address the FG puzzle in a sticky price model. Next, I propose an alternative framework which is motivated by the opposing implications of FG (i.e. it could either be interpreted as Delphic or Odyssean) and could easily be introduced in a sticky price model to address the FG puzzle. Finally, I describe a standard sticky information model with inattentive consumers and firms.

1.3.1 Baseline Sticky Price Model

The baseline model is a canonical three-equation standard sticky price model as in Gali (2008). The full description of the model is presented in Appendix A. This section displays the equilibrium conditions of the baseline sticky price model in which the FG puzzle emerges.

The standard dynamic IS curve of the baseline model is given below.

$$y_t = \mathbb{E}_t[y_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]) \tag{2}$$

where y_t, π_t and i_t denote the output gap, inflation and the nominal interest rate respectively. All are measured as deviations from the zero inflation steady state. σ is the CRRA. The standard NKPC is presented as:

$$\pi_t = \beta\,\mathbb{E}_t[\pi_{t+1}] + \kappa y_t \tag{3}$$

where $\kappa \equiv \frac{\theta_p}{(1-\theta_p)}(1-(1-\theta_p)\beta)(\sigma+\varphi)$. φ is the inverse elasticity of labor supply to wages and θ_p is the inverse price stickiness parameter, i.e. θ_p fraction of the firms update their prices each t.

I define a Taylor rule to close the model. The interest rate responds to both inflation and the output gap. It has a standard policy shock term along with a future policy shock term.

$$i_t = \phi_\pi \pi_t + \phi_y y_t + \varepsilon_t + \sum_{k=1}^{K} \varepsilon^a_{k,t-k} \tag{4}$$

where $\varepsilon^a_{k,t-k}$ is a future policy shock announced at time $t-k$ but affects the policy rule in k periods. The FG shock announced at time $t-K$ conveys information about the path of the policy rate in the next K periods. ε_t is a standard policy shock used to cancel out the Taylor rule implied response for the periods that the FG shock conveys information about, i.e. for K periods. Hence, the nominal interest rate follows the announced path (e.g. the black line in Figure 1) for K periods and follows the Taylor rule afterwards.

Equations (2)-(4) with relevant initial conditions define the sticky price equilibrium.

1.3.2 Adding Bounded Rationality

I employ the BR framework proposed by Gabaix (2020) as it is the best performing discount mechanism for addressing the FG puzzle among the most cited papers within this line of literature. Other most cited papers that introduce a single discount mechanism are Del Negro et al. (2015), McKay et al. (2017) and Angeletos and Lian (2018). While the approach of Del Negro et al. (2015) is criticized by McKay et al. (2017) for requiring implausibly large dying probabilities to match the data, the method of McKay et al. (2017) only discounts the dynamic IS curve and uses a standard NK Phillips curve. Although the lack of common knowledge as in Angeletos and Lian (2018) discounts both the Phillips curve and the IS curve, the cognitive discount factor introduced by Gabaix (2020) is more powerful in terms of the induced change in impulse responses per a unit change in the discount parameter.[13]

More intuitively, the future expectations formed by agents and firms in response to an FG shock could, in principal, suffer from cognitive myopia. This could be tested by matching the empirical impulse responses of macroeconomic variables by choosing the degree of BR, i.e. the cognitive discount factor, of households and firms.[14]

I define boundedly rational households and firms by introducing a single cognitive discount factor, $\mu < 1$, to represent BR while forming their future expectations as in Gabaix

[13]Note that the level-k thinking BR as in Farhi and Werning (2019) is also weaker than the BR introduced in Gabaix (2020), even when it is complemented with incomplete markets for $k > 1$.

[14]Section 4.4 explains the estimation methodology in detail.

(2020). The relationship between the BR expectations operator and the rational expectations (RE) operator is as follows:

$$\mathbb{E}_t^{BR}[x_{t+k}] = \mu^k \mathbb{E}_t[x_{t+k}] \tag{5}$$

where $k \geq 0$ and for any time varying x_t. Under RE $\mu = 1$ while $\mu < 1$ under BR. Note that agents have RE for the steady state variables. BR is with respect to agents' perception of deviations from the steady state.

Given the BR framework, the discounted dynamic IS curve can be derived as:

$$y_t = \mu \mathbb{E}_t[y_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]) \tag{6}$$

Notice that this formulation proposed by Gabaix (2020) assumes that boundedly rational agents can correctly perceive the real interest rate (hence the expected inflation of the next period). Thus, the rational Fisher equation holds in the agent's perception of the world.[15]

The NKPC under BR can be derived as proposed by Gabaix (2020):

$$\pi_t = \beta \mu^f \mathbb{E}_t[\pi_{t+1}] + \kappa y_t \tag{7}$$

where $\mu^f \equiv \mu\left((1-\theta_p) + \frac{1-\beta(1-\theta_p)}{1-\beta(1-\theta_p)\mu}\theta_p\right)$. Notice that the coefficient on future infla-

[15]Note that the alternative assumption of discounting $\mathbb{E}_t[\pi_{t+1}]$ does not change the conclusion of this paper. The implied cognitive discount factor, μ, increases by around 10 bps in this alternative specification.

tion depends on price stickiness unlike the standard model. Under BR, inflation is more forward-looking when prices are stickier.

Equations (4), (6) and (7) with relevant initial conditions define the equilibrium for the sticky price model with BR.

1.3.3 Adding a Probability of Delphic Interpretation

In this section, I introduce a novel framework as an alternative to the proposed discount frameworks (e.g. introducing BR) to address the FG puzzle. Instead of deviating from standard assumptions (e.g. full information, rational expectations, complete markets), the proposed framework introduces an alternative interpretation of FG communication.

Campbell et al. (2012) coined the terms Delphic and Odyssean FG in reference to Homer's epic, Odyssey. Delphic FG refers to the component of a policy announcement in which the public learns about the future expectations of the central bank regarding the macroeconomic outlook whereas Odyssean FG is the commitment of the central bank to a particular path for the policy rate, independent of the future macroeconomic conditions.

Nakamura and Steinsson (2018) document that growth expectations in the US are adjusted upwards in response to a monetary policy tightening and downwards following a policy easing.[16] As the conventional impact of monetary policy surprises on growth is in the opposite direction, Nakamura and Steinsson (2018) argue for the existence of an alter-

[16]Campbell et al. (2017) show the same result for unemployment expectations.

native channel through which monetary policy impacts the economy. They call this the Fed information effect, i.e. the information revealed by the Fed through its policy announcements. As the revealed information is about the state of the economy, the Fed information effect can be referred to as the Delphic FG channel.

Nakamura and Steinsson (2018) propose to capture the macroeconomic information content of monetary policy announcements by assuming that the change in the announced path of the policy rate linearly impacts the future path of the natural rate of interest. I estimate their model by choosing the parameter that governs the extent to which monetary policy announcements have information effects versus traditional effects and find it as 0.98. Hence, the policy announcement should be almost fully Delphic (or interpreted as almost fully Delphic) to match the data. Since this is an implausible result for the US, I propose an alternative way of introducing a Delphic FG channel in a standard NK model, in which an FG easing lowers private agents' expectations of the future path of macroeconomic variables. Then, I show that this framework is able to match the data with empirically plausible structural parameters.

Defining Delphic Interpretation

Equation (4) defines FG as an exogenous shock to the nominal interest rate path in the absence of a Taylor rule for K periods, i.e. as Odyssean FG. The baseline model assumes that all agents understand that the FG shock is Odyssean, i.e. the announced change in the nominal interest rate path is due to an exogenous shock. I relax this empirically questionable assumption by allowing for uncertainty about the nature of the FG shock. Agents allocate a probability, ψ, to an announced interest rate path being an endogenous response to a change in the central bank's expectations of the future paths of output and inflation (Delphic FG). With probability $1-\psi$, agents believe that the announced interest rate path is exogenous (Odyssean FG). Formally, I define Delphic interpretation as follows:

Delphic Interpretation. *Delphic interpretation is the attribution of the announced interest rate path, $\sum_{k=1}^{K}\varepsilon^{a}_{k,t-k}$, to the central bank's reaction function, $\phi_\pi\pi_t+\phi_y y_t$. Given the announced interest rate path, agents update their expectations of the future path of y_t and π_t such that:*

$$\varepsilon^{a}_{k,t-k}=\phi_y\,\mathbb{E}_{d,t}[y_{t+k}]+\phi_\pi\,\mathbb{E}_{d,t}[\pi_{t+k}] \qquad k\in 1,2,\ldots,K \tag{8}$$

Hence, the announced interest rate path is an expectation shock as well as a monetary policy shock under Delphic interpretation.

Equation (8) and the NKPC imply a particular future path of output under Delphic interpretation:

$$\mathbb{E}_{d,t}[y_{t+k}]=\frac{1}{\phi_y}\varepsilon^{a}_{k,t-k}-\frac{\kappa\phi_\pi}{\phi_y}\sum_{j=0}^{\infty}\beta^{j}\,\mathbb{E}_{d,t}[y_{t+k+j}] \tag{9}$$

Notice that the FG shock specified in Equation (4) is Odyssean. Hence, the Delphic interpretation of the announced interest rate path is, in fact, a false interpretation. As discussed in Nakamura and Steinsson (2018), the presence of a Delphic channel through which output expectations are adjusted in the opposite direction is consistent with the US data. By introducing a Delphic channel aside from the conventional monetary policy transmission channel, the framework proposed in this section would be able to address the FG puzzle.

A NK Model with Delphic Interpretation

Given the implied decrease in the future path of y_t following an FG easing under Delphic interpretation, I assume that households decrease their consumption paths by the inferred decrease in the expected output path. Hence, the expected lower path of y_t as expressed in Equation (9) is introduced as a negative shock to the dynamic IS curve and is scaled by the probability of Delphic interpretation, ψ, as follows:

$$y_t = \mathbb{E}_t[y_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]) + \psi \left[\frac{1}{\phi_y} \sum_{k=1}^{K} \varepsilon^a_{k,t-k} - \frac{\kappa \phi_\pi}{\phi_y} \sum_{j=0}^{\infty} \beta^j \, \mathbb{E}_{d,t}[y_{t+k+j}] \right] \tag{10}$$

Note that with probability $\psi \in [0,1]$, agents interpret an announced interest rate path as Delphic. When there is no Delphic interpretation ($\psi = 0$), Equation (10) reduces to the standard dynamic IS curve as there is no macroeconomic information content of the FG shock. In the presence of Delphic interpretation ($\psi > 0$), there are two opposing channels. The conventional channel implies a higher output path in response to an FG easing while the Delphic interpretation lowers the output path by the inferred decrease in the expectations of the future path of output, as described in Equation (9).

I assume that the central bank is not strategically reacting to a possible Delphic interpretation of the FG shock.[17] For simplicity, I assume that all agents are risk neutral. Thus,

[17] Otherwise, for a large ψ, the central bank might strategically bias its FG. However, agents might learn

agents are not prone to any costs regarding the uncertainty associated with the nature of the FG shock. The optimal pricing behavior does not change since the sensitivity of prices to the real marginal cost is the same. Thus, the NKPC, as given in Equation (3), holds in equilibrium. Note that the NKPC relationship implies a lower future path for inflation given a decrease in the expected future path of output.

Equations (3), (4) and (10) with relevant initial conditions define the equilibrium for the sticky price model with a probability of Delphic interpretation.

1.3.4 Sticky Information Model

An alternative approach proposed in the FG puzzle literature is to employ a sticky information model. This section describes a general equilibrium model as presented in Reis (2009) and, Khan and Zhu (2002). There is no nominal rigidity in this model since prices are not sticky. Instead, there is information stickiness. Since information is costly to obtain, absorb and process each period, agents optimally choose not to update their information set every period. The main difference between the two models is the timing of the expectations in key equations. While the previous model is built on today's expectations of future variables, this model operates through the past and current expectations of today's variables.

Households

In a sticky information model, consumers optimally choose to update their information

how to interpret announcements and adjust for the bias as pointed out by Nakamura and Steinsson (2018).

set sporadically since there is a fixed cost of acquiring information (Reis, 2006). Only δ fraction of consumers update their information every period. I do not distinguish a unit of household into a consumer and a worker who update their information sets at different paces. In Appendix B, I introduce this distinction in order to show that the sticky information model can still explain the puzzle in the presence of information stickiness in the labor market. Appendix B further shows that introducing wage stickiness in the sticky price model, with or without BR, does not suffice to match the empirical impulse responses.

For the δ fraction of the consumers who update their information set at a given period, the optimal intertemporal consumption path follows the standard Euler equation:

$$c_{t,0} = \mathbb{E}_t[c_{t+1,0}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]) \tag{11}$$

For the remaining consumers, the consumption at time t is what they thought the optimal consumption would be last time they updated their information set (j periods ago):

$$c_{t,j} = \mathbb{E}_{t-j}[c_{t,0}] \tag{12}$$

Thus, the aggregate consumption is

$$c_t = \delta \sum_{j=0}^{\infty} (1-\delta)^j \, \mathbb{E}_{t-j}[c_{t,0}]. \tag{13}$$

Firms

Unlike the Calvo price setting, all firms can update their prices every period. However, some firms optimally choose not to update their information sets every period. Firms update their information at the rate of θ_p, the same as the inverse price stickiness parameter in the previous model. For a firm that last updated its information set i periods ago, the price that it chooses at time t is what the firm thought the optimal price would be at time t. The optimal price can be expressed as in Khan and Zhu (2002):

$$p_t^* = p_t + \Omega y_t \tag{14}$$

where $\Omega = \frac{\sigma+\varphi}{1+\varphi\varepsilon}$.

Equilibrium

Using the optimal price in (14), the Phillips curve can be expressed in terms of the CPI price level.

$$p_t = \theta_p \sum_{i=0}^{\infty} (1-\theta_p)^i \, \mathbb{E}_{t-i} \left[p_t + \Omega y_t \right] \tag{15}$$

Alternatively, the Phillips curve can be expressed in terms of inflation:

$$\pi_t = \frac{\theta_p}{1-\theta_p} (\Omega y_t) + \theta_p \sum_{i=0}^{\infty} (1-\theta_p)^i \, \mathbb{E}_{t-i-1} \left[\pi_t + \Omega \Delta y_t \right] \tag{16}$$

In the savings market, the sticky information IS curve can be derived as in Reis (2009):

$$y_t = \delta \sum_{i=0}^{\infty} (1-\delta)^i \mathbb{E}_{t-i} \left[y_\infty - \frac{1}{\sigma} \mathbb{E}_t \sum_{\tau=0}^{\infty} (i_{t+\tau} - (p_{t+1+\tau} - p_{t+\tau})) \right] \tag{17}$$

where $y_\infty = \lim_{\tau \to \infty} \mathbb{E}_t (y_{t+\tau})$ is the long-run equilibrium output.

Equations (4), (15) and (17) together with relevant initial conditions define the sticky information equilibrium.

1.4 Calibration and Estimation

The metric used for the "horse-race" among the described models is impulse response matching. For each model, I choose the particular structural parameter of the given specification (i.e. cognitive discount factor, probability of Delphic interpretation or the information update frequency of households) that best matches the empirical impulse responses of macroeconomic variables to an FG surprise. I use local projections to obtain the empirical impulse responses as in Jordà (2005).[18]

I describe the data in Section 4.1, the local projections estimation in Section 4.2, the baseline calibration in Section 4.3 and the estimation methodology in Section 4.4.

[18] Matching covariances or structural VAR impulse responses are common methods in this line of literature. While the former approach does not allow for structural interpretations, the latter is constrained by the invertibility of the VAR and is sensitive to the model specification. As discussed in Stock and Watson (2018), the invertibility assumption, i.e. the assumption that structural shocks can be recovered from current and lagged values of the data, is non-trivial and a structural VAR is not consistent without this assumption. Although the local projections approach is not as efficient as a structural VAR with external instruments, it does not depend on the invertibility assumption and is consistent, assuming that the empirical FG surprise is correctly identified using intraday data under the efficient market hypothesis prior.

1.4.1 Data

My dataset spans the first ZLB period in the US, which is from January 2009 to October 2015. In order to estimate the empirical impulse responses of the key macroeconomic variables in the US, I use log monthly CPI level and log monthly industrial production data.[19] As for the number of hours worked, I use the log average weekly hours of production and nonsupervisory employees. To capture the impact of an FG surprise on the interest rate expectations in the US, I use the high-frequency response of the first 8 Eurodollar futures rates, which spans roughly the interest rate expectations in the US for the next two years.

1.4.2 Local Projections: Empirical Impulse Responses

The empirical responses of macroeconomic variables to an FG surprise are obtained through local projections as in Jordà (2005):

$$\Delta M_{t+h} = \beta_0^i + \beta_{FG}^h FG_t + \beta_{LSAP}^h LSAP_t + \beta_{control}^h \Delta M_{t-i}^m + \varepsilon_t^h \tag{18}$$

where ΔM_{t+h} is the change $(M_{t+h} - M_{t-1})$ of the macroeconomic variables following an FOMC announcement at different horizons $h \in \{0, 1, ..., 8\}$. FG_t and $LSAP_t$ surprises are identified as described in Section 2.2. ΔM_{t-i}^m, $i \in \{1, 2, 3\}$, which is the collection of preceding monthly changes of the dependent variable in the three months before the announcement, is the set of control variables. The purpose of these control variables is to decrease

[19] I use the manufacturing industrial production index which excludes mining, and electric and gas utilities.

the sampling variance of the estimator by decreasing the variance of the error term. The coefficient estimates are still consistent in the absence of these control variables since the FG surprise, which is identified using high-frequency data, should be independent of true past and future monetary policy shocks. Since the model is calibrated at a quarterly frequency, the local projections are conducted quarterly (starting from the instantaneous impact up to a two-year horizon).

I use β^h_{FG} in order to construct the empirical responses of macroeconomic variables at different horizons. For $h = 0$, I use monthly responses. I use Newey-West standard errors in order to control for autocorrelation. The maximum lag allowed in each horizon is $1.5 \times h$.

I employ the empirical impulse responses of three macroeconomic variables: output, inflation and hours worked. While the responses of output and inflation are commonly studied in the FG puzzle literature, the responses of working hours is also studied (e.g. Campbell et al. (2019)) as a significant indicator of the real sector response to an FG surprise. The employed models also have substantive implications for the number of hours worked. The impulse responses obtained by the industrial production data is the empirical counterpart of y_t. The CPI level, and the average weekly hours of production and nonsupervisory employees correspond to p_t and n_t, respectively.

1.4.3 Baseline Calibration

Table 1 shows the baseline calibration of the model. The model is calibrated at a quarterly frequency. The discount factor β is standard and implies a discount rate of 1% per quarter. The CRRA parameter σ is 1, implying log utility. Frisch elasticity of labor supply φ is calibrated to 1, following Gali (2008). Under baseline calibration, production function is constant returns to scale and cognitive discount factor μ is 1, implying RE. The coefficients of inflation and output in the Taylor rule, ϕ_π and ϕ_y, are standard in the literature following Taylor (1999). Intratemporal elasticity among goods implies a steady state markup of 20%. The fraction of firms which update their information set (prices) in the sticky information model (sticky price model) is calibrated to 0.25, implying an average duration of one year for the price level. In the sticky information model, the rate at which consumers update their information set under the baseline calibration is 0.08, a value estimated by Reis (2009). All results presented in Section 5 are robust to this empirically plausible baseline calibration of structural parameters.

1.4.4 Estimation Methodology

I estimate a given model by choosing the structural parameters of interest (the cognitive discount factor μ, the Delphic interpretation probability ψ, or the information update frequency of consumers δ) that minimize the quadratic distance between the model-implied impulse responses of macroeconomic variables to an FG shock and their empirical counterparts which are obtained through local projections. The minimized quadratic function has a χ^2 distribution with $k-p$ degrees of freedom, where k and p are the lengths of Φ_{data} and θ respectively:

$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}}(\Phi_{data} - \Phi_{model}(\theta))'V^{-1}(\Phi_{data} - \Phi_{model}(\theta)) \tag{19}$$

where Φ_{data} is the vector of empirical impulse responses of macroeconomic variables to an FG surprise over different horizons and $\Phi_{model}(\theta)$ is the model-implied impulse responses of these variables given the vector θ, which includes the structural parameters to be estimated, μ, ψ or δ. All of these variables are defined over [0, 1]. V is the variance-covariance matrix of the empirical impulse responses, Φ_{data}. The covariances are across horizons and macroeconomic variables. Empirical confidence intervals (CIs) are formed using these standard errors while the model-implied CIs employ GMM standard errors for an over-identified case: $k \geq p$. The estimated structural parameters $\hat{\theta}$ are asymptotically normal with the variance-covariance matrix:

$$\frac{1}{T}(D'V^{-1}D)^{-1} \tag{20}$$

where T is the sample size and $D = \frac{\partial \Phi_{model}(\theta)}{\partial \theta}$. Using the delta method, one can obtain the asymptotic distribution of the model-implied impulse responses:

$$\sqrt{T}(\Phi_{model}(\hat{\theta}) - \Phi_{model}(\theta)) \xrightarrow{d} N(0, D(D'V^{-1}D)^{-1}D') \tag{21}$$

where the length of $\Phi_{model}(\theta)$ is the estimation horizon times macroeconomic variables. I use the asymptotic variance-covariance matrix to construct CIs for the model-implied impulse response functions.

1.5 Addressing the Forward Guidance Puzzle

1.5.1 The Sticky Price Model

First, I illustrate the FG puzzle as the mismatch between the empirical and model-implied impulse responses of macroeconomic variables to a one-period FG shock under the baseline sticky price model. Figure 5 shows the drastic responses of output, price level and working hours to a one-period FG shock, which moves the 8-quarter-ahead interest rate expectations by 25 bps (the red shock), under the baseline sticky price model described in Section 3.1.[20] The corresponding χ^2 test statistic, which is the value of the objective function given in equation (19), is reported in Table 2.[21] Clearly, the empirical and model-implied impulse

[20]Note that the model-implied impulse responses do not have a CI since the model is fully calibrated.

[21]As discussed in Section 4.2, I employ the empirical impulse responses of three macroeconomic variables over a two year horizon. These test statistics are estimated using the fit of output, the CPI level and working hours over a two-year horizon.

responses are significantly different from each other. Due to its forward looking nature, the sticky price model implies large jumps in macroeconomic variables. The magnitude of these instantaneous responses are much larger than the empirical responses of these macroeconomic variables to an FG surprise over a two year horizon.

Section 2 shows that an FG shock which moves the 8-quarter-ahead interest rate expectations also moves interest rate expectations at preceding horizons significantly, both statistically and economically, in the US during the first ZLB period. Thus, using an estimated FG shock (the black shock), one can measure the degree to which the FG puzzle gets larger. Figure 5 also plots the model-implied responses of macroeconomic variables to an estimated FG shock under sticky prices and RE. It can clearly be seen that the instantaneous responses of all variables are more than two times larger while the quadratic distance between the empirical and model-implied impulse responses (the χ^2 test statistic) gets more than five times larger as presented in Table 2. Hence the FG puzzle gets much more difficult to address.

1.5.2 Adding Bounded Rationality in the Sticky Price Model

In this subsubsection, I discuss whether introducing BR in a sticky price model is sufficient to fully explain the FG puzzle implied by an estimated FG shock.

First, I discuss whether adding BR to a sticky price model is sufficient to address the FG puzzle implied by a one-period FG shock. In particular, I estimate the sticky price model with BR by choosing the cognitive discount factor, μ, that minimizes the distance between the empirical and model-implied impulse responses. Table 2 reports that the corresponding χ^2 test statistic is 17, implying that the empirical and model-implied impulse responses are not statistically different from each other.[22] Table 3 presents the estimated cognitive discount factor as 0.59, an empirically plausible value which is close to the one estimated by Gabaix (2020).[23] Note that the cognitive discount factor is estimated very precisely given the restrictions of the model where the only source of uncertainty is the FG shock. Thus, unlike the empirical CIs which are obtained through model-free local projections and are prone to various sources of uncertainty, the model-implied CIs are very tight.

Next, I show that the BR framework is not sufficient to fully explain the FG puzzle implied by an estimated FG shock. Figure 6 plots the model-implied impulse responses. As reported in Table 3, the model-implied impulse responses still match the data. However, the implied cognitive discount factor, μ, is implausibly small: 0.21.[24] Figure 9 plots the implied fit of the model $\forall \mu \in [0,1]$. For any $\mu > 0.42$, the model-implied impulse responses cannot match their empirical counterparts at the 5% significance level. Hence, even the largest μ that the model needs to marginally fit the data is implausibly small.

[22] The critical value with 26 degrees of freedom (number of moments matched minus the number of estimated parameters) is 38.89 at the 5% significance level.

[23] Gabaix (2020) employs a Bayesian estimation for the US with a macroeconomic dataset that spans more than five decades. For the case where all agents suffer from cognitive myopia by the same amount, he finds the cognitive discount factor, μ, as 0.64 with a 95% confidence interval of [0.42, 0.83].

[24] It is well below the discount factor estimated by Gabaix (2020) whose mean estimate is 0.64 with a standard error of 0.11. More intuitively, it implies that the BR expectations of any deviation from the steady state is almost *three* orders of magnitude smaller than its RE counterpart over a yearly horizon.

If separate cognitive discount factors are estimated for households and firms simultaneously, the estimated cognitive discount factor is 0 for households and 0.65 for firms.[25] Hence, the implausibly small cognitive discount factor is driven by the mismatch between the empirical and model-implied impulse responses of output and working hours.

I conclude that the approach of introducing a particular discount mechanism in a sticky price model is not sufficient to fully explain the FG puzzle *per se* since the discussed BR framework is the best performing discount mechanism among the most cited papers.[26]

1.5.3 Adding Delphic Interpretation in the Sticky Price Model

Next, I explore the implications of allowing agents to interpret an FG shock as Delphic with a certain probability on addressing the FG puzzle implied by an estimated FG shock.

Note that the decomposition of central bank communication into Delphic and Odyssean components has crucial implications for monetary policy. If a central bank is intended to stimulate the economy by committing itself to an interest rate path, the Delphic interpretation creates unintended consequences as macroeconomic expectations, such as inflation or growth, are adjusted downwards. Motivated by this discussion in the FG literature, I show that allowing for a plausible probability of Delphic interpretation in a sticky price model is sufficient to explain the FG puzzle implied by an estimated FG shock.

[25] As expected, the model fits the data better ($\chi^2 = 12$) with an additional free parameter.

[26] Note that introducing multiple discount mechanisms (e.g. lack of common knowledge as in Angeletos and Lian (2018) or uninsurable income shocks as in McKay et al. (2016)) would clearly imply larger discount factors to match the empirical impulse responses.

I estimate the sticky price model with Delphic interpretation by choosing the probability of Delphic interpretation, ψ, that minimizes the quadratic distance between the model-implied and empirical impulse responses. Table 3 presents the estimated Delphic interpretation probability, ψ, as 0.39 when other parameters are calibrated to their baseline values in Table 1. This is an empirically plausible estimate for the US.[27] The χ^2 test statistic implies that the model-implied impulse responses are not significantly different from their empirical counterparts. Figure 7 plots the model-implied and empirical impulse responses.[28] As presented in Figure 9, the model fits the data well for any $\psi \in [0.33, 0.50]$. These results are robust to alternative calibrations of other parameters as reported in Table 4.

By introducing uncertainty regarding the nature of the FG communication, I show that a plausible probability of Delphic interpretation is sufficient to explain the larger FG puzzle. Thus, this novel framework, which is motivated by the opposing implications of committing to a lower interest rate path on future macroeconomic expectations, is a useful tool that can be embedded in the baseline sticky price model to explain the FG puzzle.

[27] Following Campbell et al. (2017), I empirically identify the Delphic component of FG surprises in the US for the ZLB period (ending in 2014 due to the five year lag in the Greenbook data). I find that the size of the Delphic component is around a third of the size of the FG surprise.

[28] As ψ is estimated very precisely with a standard error of 0.002, the model-implied CIs are very tight.

1.5.4 The Sticky Information Model

After proposing an effective framework that explains the FG puzzle which emerges in a standard sticky price model, I discuss whether an alternative source of nominal rigidity proposed in this line of literature can also address the larger FG puzzle.

The sticky information model deviates from the fully forward looking nature of standard sticky price models. This is due to a different set of assumptions. For instance, since only a fraction of firms can update their prices under Calvo (1983) pricing, they choose the average optimal price in the near future. Under sticky information assumption, since all firms can update their prices, they choose the optimal price of the current period. However, only a fraction of them choose to make a fully informed decision (due to the cost of obtaining information) while others use previously available information. Thus, while inflation and output are determined by future expectations under sticky price models, they are pinned down by the sum of current and past expectations of today's inflation and output under the sticky information model. Therefore, a policy shock about the future has milder effects.

Since the sticky information model is not as forward looking as the sticky price model, introducing a one-period FG shock or an estimated FG shock does not induce a significant difference in the response of macroeconomic variables. Table 2 reports that the χ^2 test statistic implied by a one-period FG shock is 18, while it is 31 in the presence of an estimated FG shock under baseline calibration. Hence, employing an estimated FG shock does not drastically change the model-implied impulse responses in the sticky information model. Note that these results are highly sensitive to the presence of inattentive consumers. When only firms have sticky information (i.e. $\delta = 1$) as often proposed in the literature, the mismatch between the model-implied and empirical impulse responses to an estimated FG shock is still large ($\chi^2 = 580$). However, the implied puzzle in the sticky information model with only inattentive firms is much smaller than the one in the standard sticky price model as highlighted in this line of literature (see e.g. Kiley (2016)).

In the presence of inattentive consumers, the fraction of consumers who update their information sets each period, δ, is calibrated to 0.08 under baseline calibration following the estimate of Reis (2009) for the US. I relax this assumption and find that the level of δ that best matches the empirical impulse responses is 0.04, as shown in Table 3. Figure 8 plots the model-implied impulse responses to an estimated FG shock under $\delta = 0.04$. Figure 9 further shows that the model can fit the data well with any information update frequency parameter, δ, of less than 10% for consumers. This result is consistent with the estimate of Reis (2009)[29] who reports a 95% CI for this parameter in the US as [0.03, 0.16].[30] Hence, I conclude that the puzzle can also be addressed by a sticky information

[29] Reis (2009) conducts a Bayesian estimation for the US data with macro data that spans two decades.

[30] Note that the estimate of Reis (2009) is smaller than the findings of the consumer survey literature which reports that households update their inflation expectations once a year in the US (see e.g. Carroll (2003)). However, setting the information update frequency parameter, δ, to 0.25 with the assumption that households attain full information once they update their information sets would create an upward bias given the implausibly low or high estimates of inflation (e.g. more than 10% for the next quarter) in consumer surveys. An additional source of upward bias implied by surveys that rely on repeat participants is learning-through-survey effects (see e.g. Kim and Binder (2020)).

general equilibrium model regardless of the type of the introduced FG shock (i.e. one-period or estimated).[31]

1.6 Conclusion

Motivated by the response of interest rate expectations to FG surprises during the ZLB period, I show that the conventional way of introducing an FG shock in the literature is not empirically plausible. Since an estimated FG shock can be captured as a sequence of future policy shocks, the implied FG puzzle is much larger than it is typically characterized in this line of literature.

Given a larger puzzle, I show that a sticky price model with bounded rationality, which is the best performing discount mechanism among those in the most cited papers within this literature, cannot fully explain the puzzle *per se* with an empirically plausible degree of bounded rationality. Instead, I show that allowing agents to update their macroeconomic expectations in the pessimistic direction following an FG easing in a standard sticky price model explains the larger puzzle. Lastly, I show that the puzzle can also be addressed by a sticky information general equilibrium model.

[31] Introducing BR or Delphic interpretation in the sticky information model does not improve its fit. Estimating δ simultaneously with μ or ψ yields the same δ while μ and ψ are estimated as 1 and 0, respectively.

Table 1: Baseline Calibration

Parameter	Value	Source
β	0.99	1% Discount Rate
σ	1	Log Utility
φ	1	Gali (2008)
ϕ_π	1.5	Taylor (1999)
ϕ_y	0.5	Taylor (1999)
ε	6	Steady state markup of 20%
θ_p	0.25	1-Year Aggregate Duration of Price
μ	1	Rational Expectations
ψ	0	No Delphic Interpretation
δ	0.08	Reis (2009)

Note: The model is calibrated at a quarterly frequency. Parameters in the lower panel are estimated in each model specification. Their baseline calibrations are given in this table.

Table 2: Model Fit under Different Cases

χ^2 Test Statistics and p-values		One-Period Shock	Estimated Shock
Baseline Sticky Price Model	χ^2	3,449	19,630
	p-value	(0)	(0)
Sticky Price Model with BR	χ^2	17	17
	p-value	(0.91)	(0.91)
Sticky Price Model with Delphic Interpretation	χ^2	19	18
	p-value	(0.83)	(0.89)
Calibrated Sticky Information Model	χ^2	18	31
	p-value	(0.88)	(0.22)
Estimated Sticky Information Model	χ^2	18	20
	p-value	(0.88)	(0.78)

Note: The critical value for 5% significance with 26 degrees of freedom (number of moments matched minus the number of estimated structural parameters) is 38.89 at the 5% significance level. χ^2 test statistics are the values of the objective function in (19). The one-period and estimated shocks are as in Figure 1.

Table 3: Estimated Values of the Structural Parameters

	μ	ψ	δ
One-Period Shock			
Sticky Prices with BR	0.59		
	(0.01)		
Sticky Prices with Delphic Interpretation		0.15	
		(0.001)	
Sticky Information			0.07
			(0.003)
Estimated Shock			
Sticky Prices with BR	0.21		
	(0.01)		
Sticky Prices with Delphic Interpretation		0.39	
		(0.002)	
Sticky Information			0.04
			(0.002)

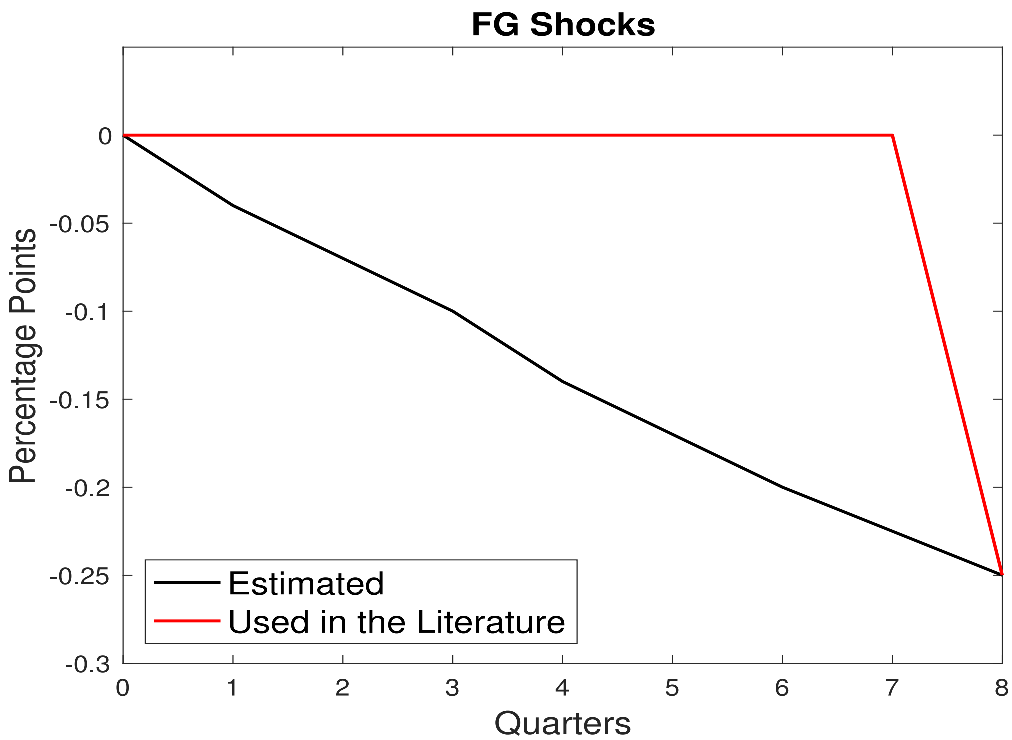
Note: Estimated GMM standard errors in parentheses. Standard errors are not valid on the boundary. The estimated values of μ, ψ and δ are the values that minimize the objective function in (19). The GMM standard errors are constructed as in (21). The one-period and estimated shocks are as in Figure 1.

Table 4: Probability of Delphic Interpretation Estimations under Different Calibrations

	$\phi_y = 0.125$	$\phi_\pi = 1.01$	$\sigma = 2$	$\varphi = 2$	$\varepsilon = 11$	$\theta_p = 0.15$
p-value	0.88	0.75	0.80	0.87	0.89	0.64
ψ	0.10	0.43	0.19	0.40	0.39	0.39
	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)

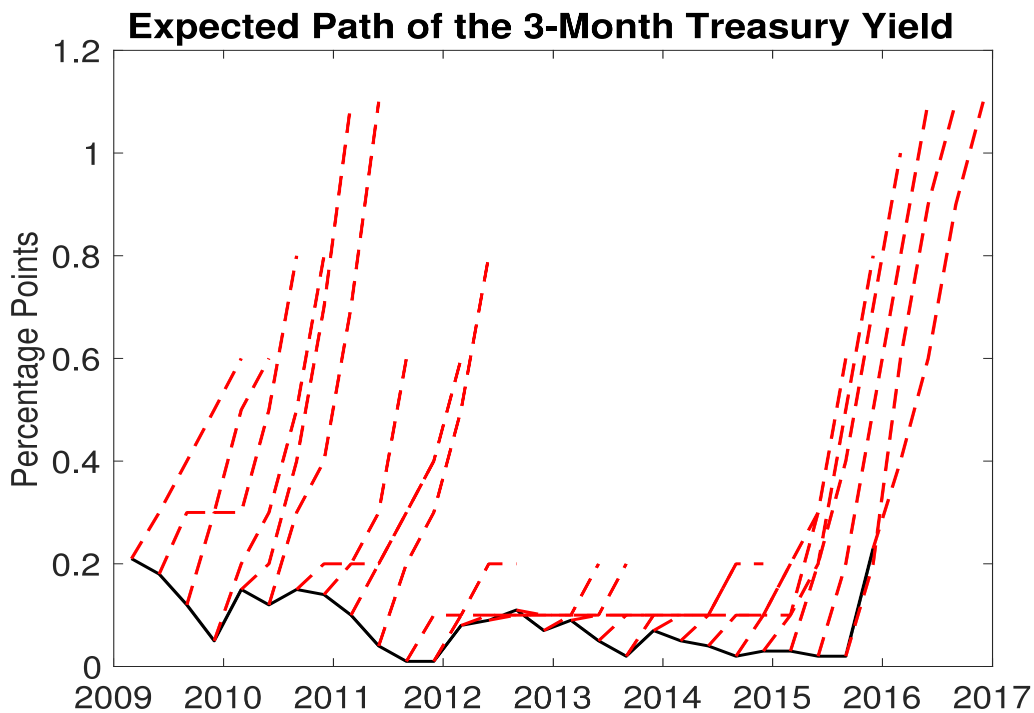
Note: Each column shows the alternative calibration of a single parameter. The remaining parameters are calibrated to their original values given in Table 1. Reported ψ values minimize the χ^2 test statistics given in (19). The p-values that correspond to the minimum χ^2 test statistics are reported. The GMM standard errors are constructed as in (21).

Figure 1: Modeling an FG Shock: One-Period vs Estimated



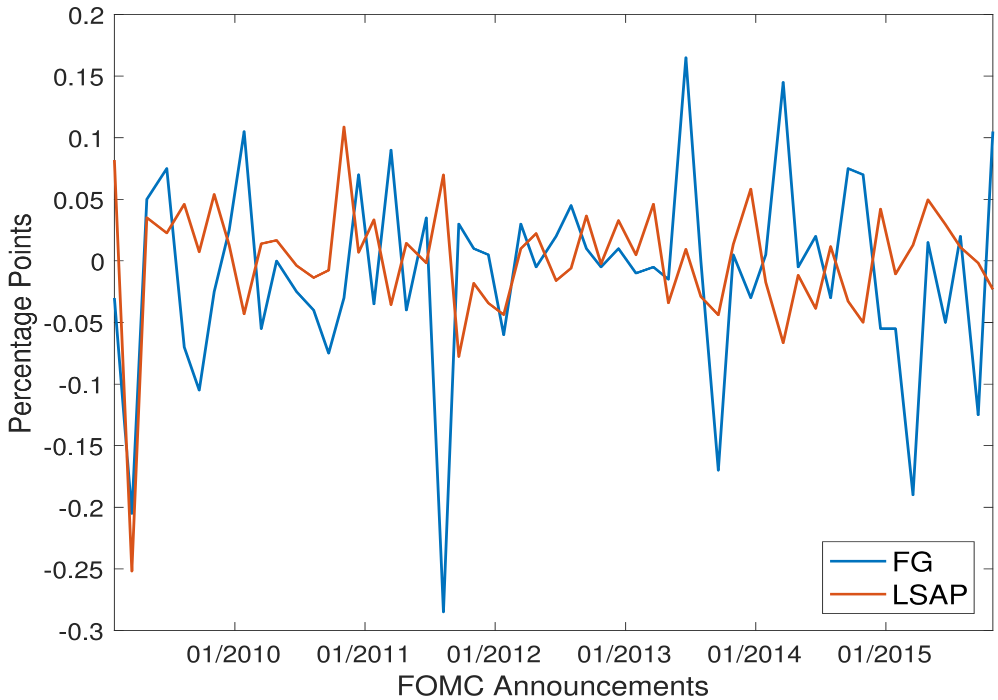
Notes: Modeled shock to the path of the nominal interest rate. The black line shows the estimated FG shock for the ZLB period while the red line shows the widely used FG shock in the literature. The black line is constructed using the coefficient estimates of the FG surprise in Equation (1).

Figure 2: Survey Expectations of the 3-Month Treasury Yield at the Zero Lower Bound



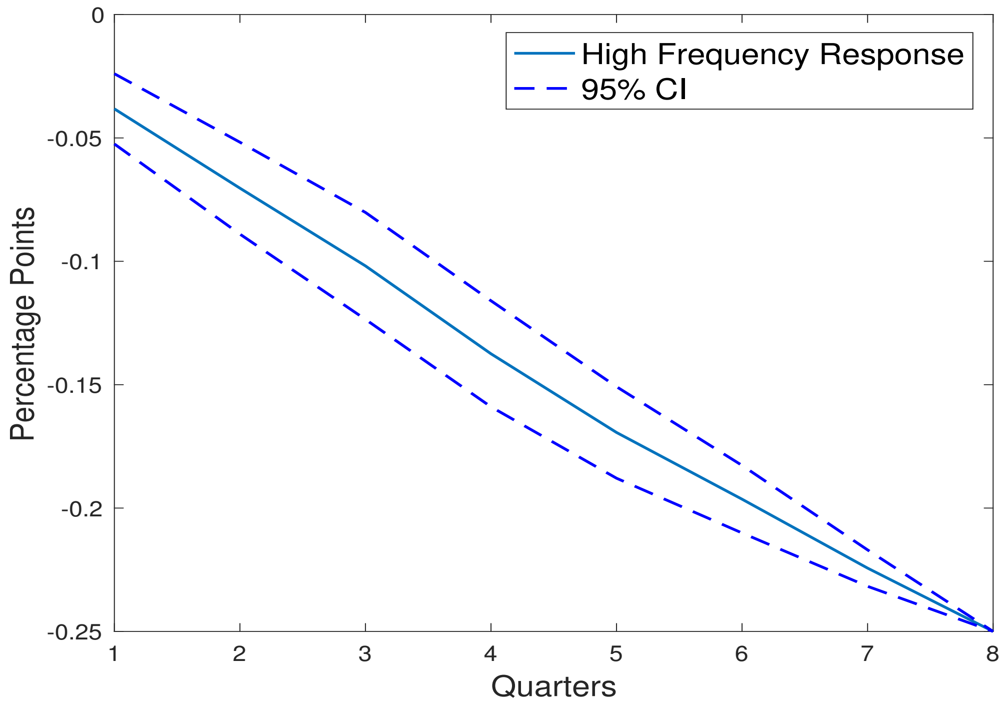
Notes: The solid black line shows the 3-month Treasury yield at the ZLB period in the US. The dashed red lines show the Bluechip survey expectations of the 3-month Treasury yield for the next four quarters.

Figure 3: Empirical FG and LSAP Surprises during the ZLB



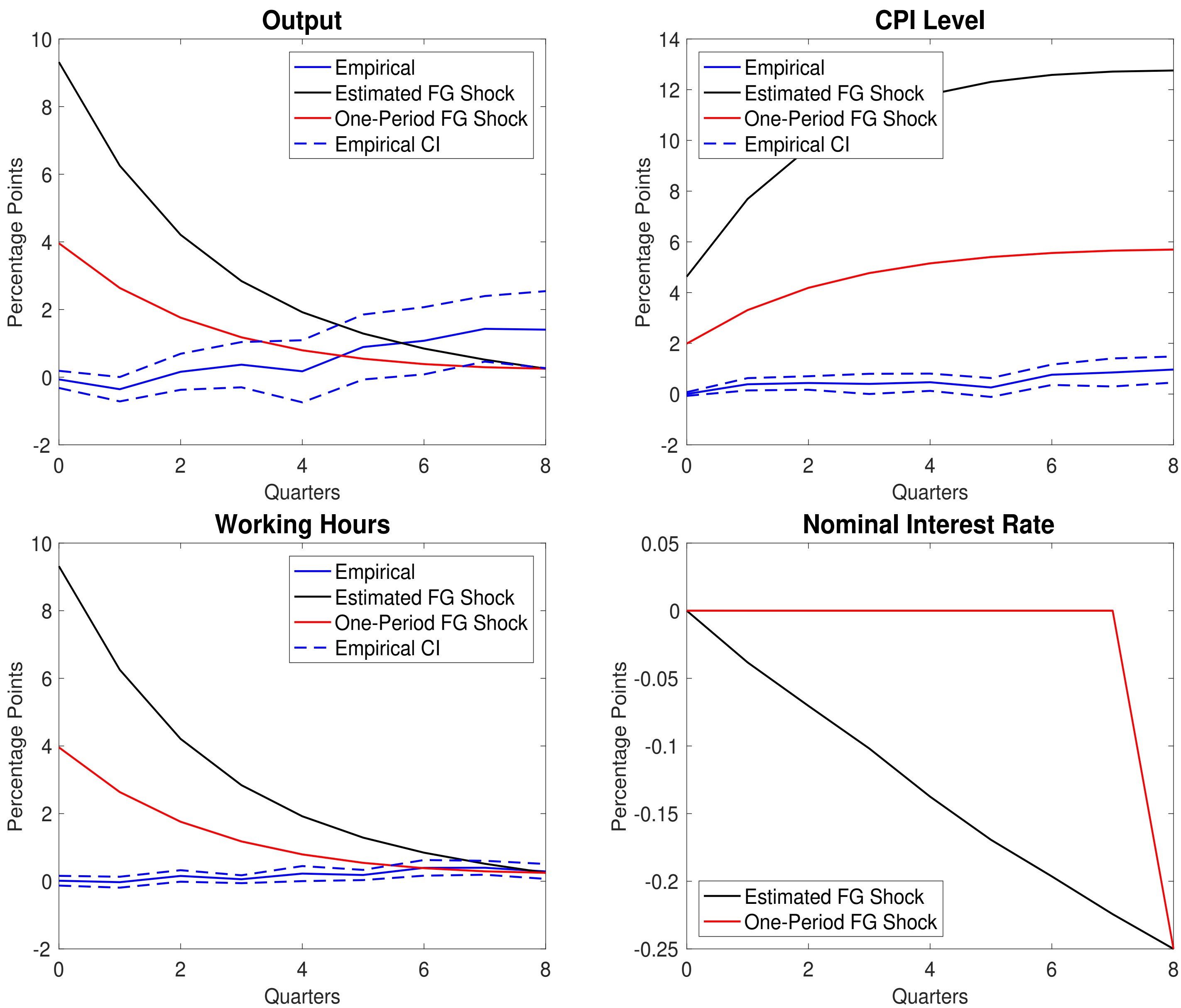
Notes: The blue line shows the FG surprise while the red line depicts the LSAP surprise for each FOMC announcement during the ZLB period. The empirical identification methodology is as described in Section 2.2. An FG surprise moves the 2-year interest rate expectations while an LSAP surprise moves the 10-year rate by the pp given on the vertical axis.

Figure 4: The Response of Interest Rate Expectations to an FG Surprise



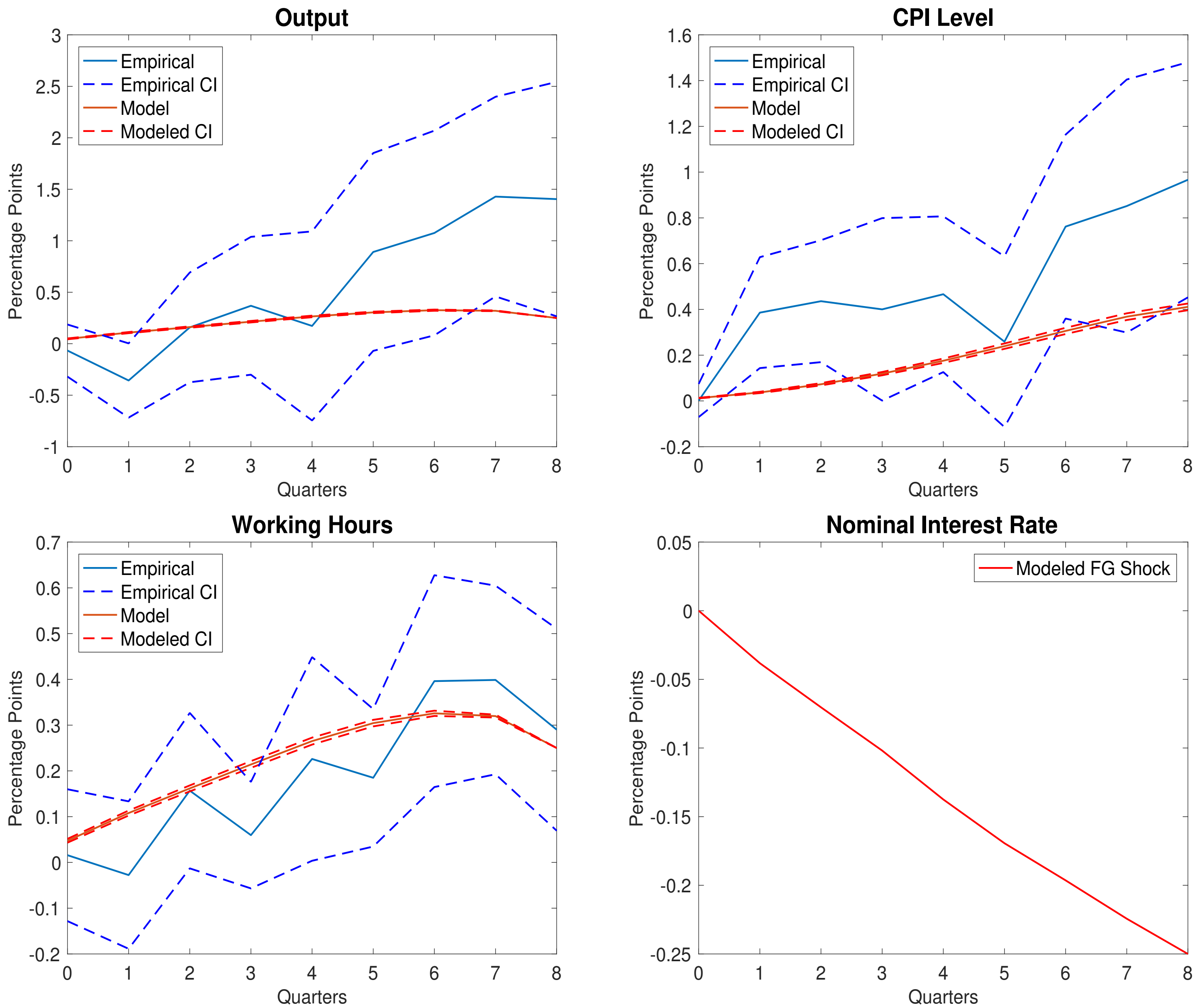
Notes: Solid line shows the coefficient estimates of the high-frequency response of the first 8 Eurodollar futures rates to an FG easing during the ZLB period as described in equation (1). It shows the change in the interest rate expectations in response to an FG surprise that moves two-year interest rate expectations down by 25 bps. The dashed lines show the 95% CIs.

Figure 5: Larger FG Puzzle: Baseline Sticky Price Model



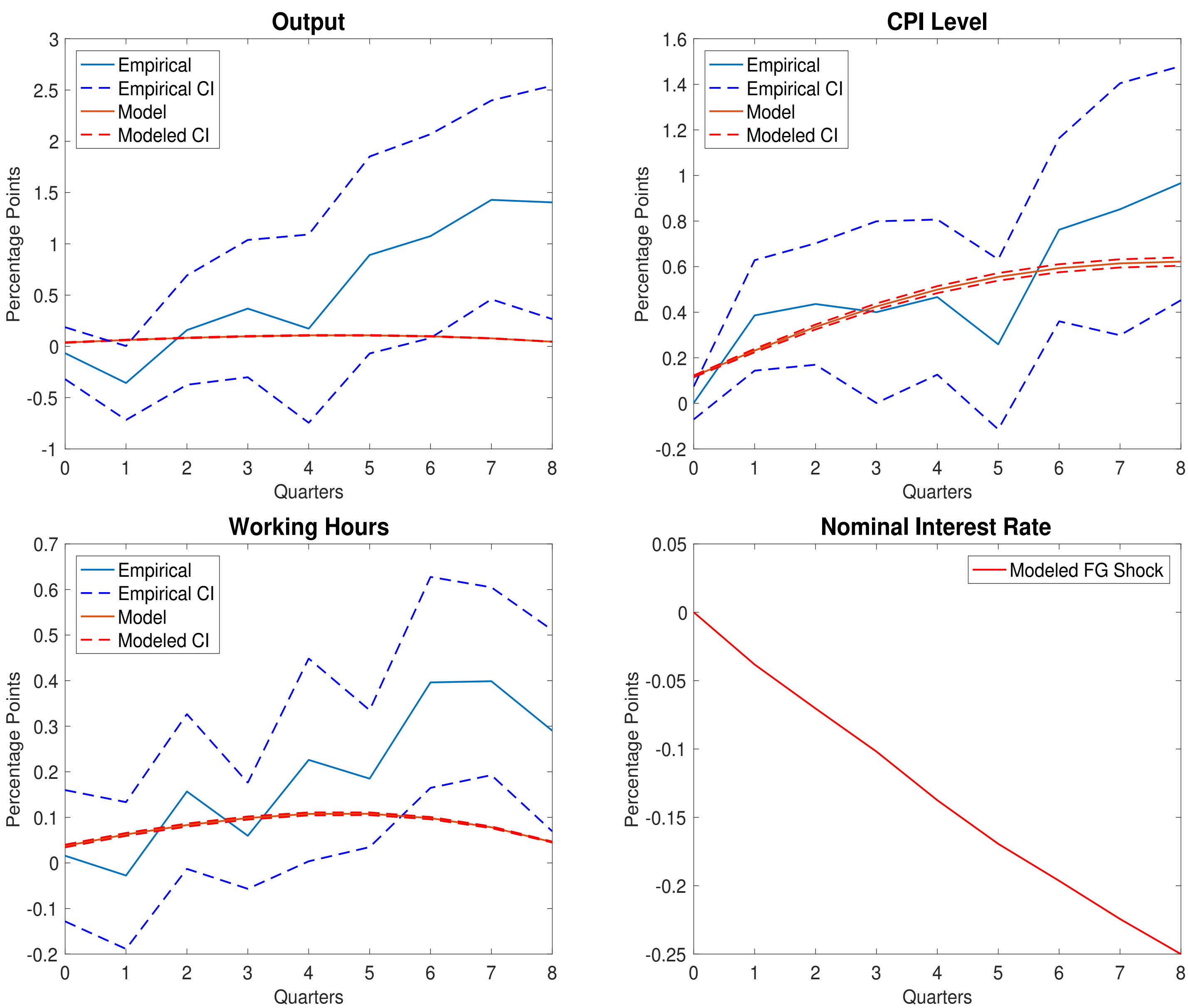
Notes: The model-implied impulse responses are under baseline calibration. The impulse responses of macroeconomic variables to an estimated FG shock are plotted in black while the responses to a one-period FG shock are plotted in red. The model-implied impulse responses do not have a CI since the model is fully calibrated. 68% CIs of the empirical impulse responses are constructed using Newey-West standard errors with a maximum lag of 1.5×horizon. The sticky price model is as described in Section 3.1.

Figure 6: Sticky Price Model with Bounded Rationality (Cognitive Discount Factor $= 0.21$)



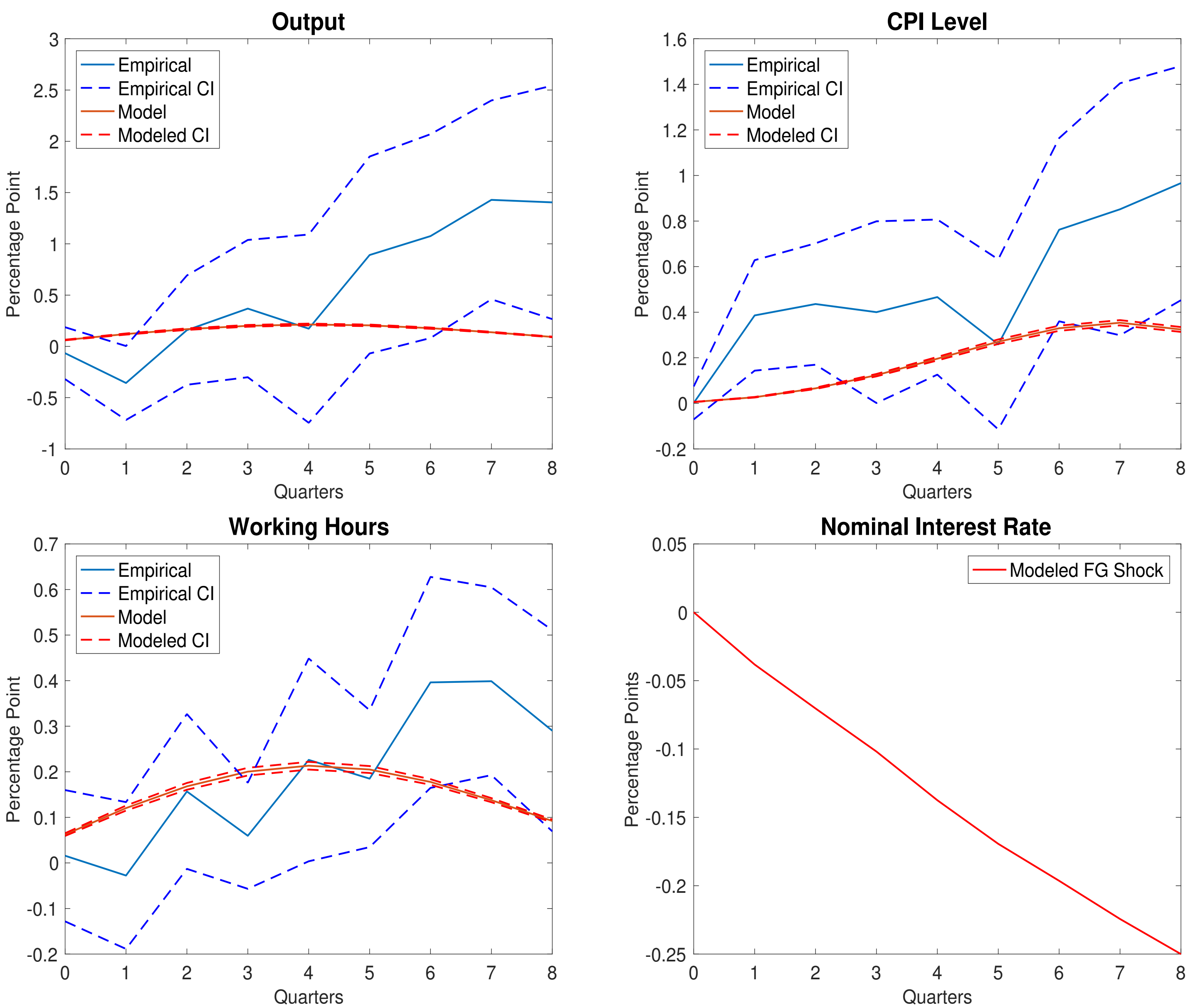
Notes: The model-implied impulse responses are under baseline calibration and estimated μ, the cognitive discount factor. GMM standard errors are used to construct the modeled 68% CIs while Newey-West standard errors with a maximum lag of $1.5\times$horizon are used to construct the empirical 68% CIs. Note that the model-implied impulse responses are estimated much more precisely than the model-free local projections since the former imposes all the restrictions of the model. The introduced shock is an estimated FG shock as the black line in Figure 1. The sticky price model with BR is as described in Sections 3.1 and 3.2. Estimated $\mu = 0.21$, implying that the BR expectations of any deviation from the steady state is almost *three* orders of magnitude smaller than its RE counterpart over a yearly horizon. Note that all variables (except for the price level) jump back to their steady states after the 8th period.

Figure 7: Sticky Price Model with Delphic Interpretation (Delphic Interpretation $= 0.39$)



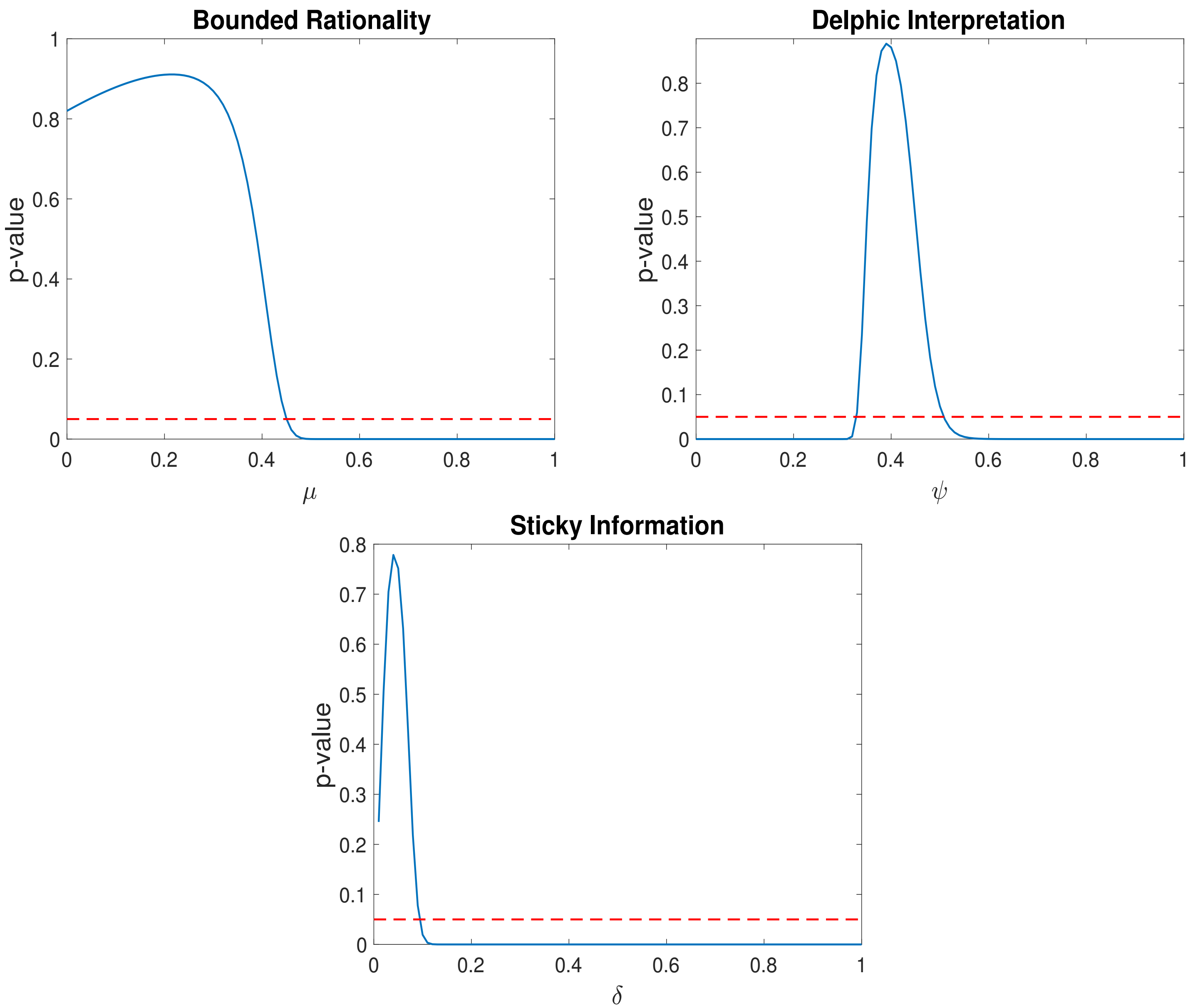
Notes: The model-implied impulse responses are under baseline calibration and estimated ψ, probability of Delphic interpretation. GMM standard errors are used to construct the modeled 68% CIs while Newey-West standard errors with a maximum lag of $1.5\times$horizon are used to construct the empirical 68% CIs. Note that the model-implied impulse responses are estimated much more precisely than the model-free local projections since the former imposes all the restrictions of the model. The introduced shock is an estimated FG shock as the black line in Figure 1. The sticky price model with Delphic interpretation is as described in Sections 3.1 and 3.3. Estimated $\psi = 0.39$, implying a Delphic interpretation of 39%. Note that all variables (except for the price level) jump back to their steady states after the 8th period.

Figure 8: Sticky Information Model (Information Update Frequency of Consumers = 0.04)



Notes: The model-implied impulse responses are under baseline calibration and estimated δ, the information update frequency of consumers. GMM standard errors are used to construct the modeled 68% CIs while Newey-West standard errors with a maximum lag of 1.5×horizon are used to construct the empirical 68% CIs. Note that the model-implied impulse responses are estimated much more precisely than the model-free local projections since the former imposes all the restrictions of the model. The introduced shock is an estimated FG shock as the black line in Figure 1. The sticky information model is as described in Section 3.4. Estimated $\delta = 0.04$, implying that 4% of consumers update their information sets every quarter. Note that all variables (except for the price level) gradually converge back to their steady states after the 8th period.

Figure 9: Test of Model Specification



Notes: The implied fit of the model under different values of μ, ψ and δ. The 5% significance level is plotted with a dashed red line. P-values above the critical value imply that the model-implied impulse responses are not statistically different from their empirical counterparts. The largest p-value indicates the structural parameter that best fits the data, i.e. $\mu = 0.21$, 0.39 and $\delta = 0.04$ (as given in Table 3).

Chapter 2

2 Unconventional Monetary Policy Surprises: Delphic or Odyssean?

2.1 Introduction

The conventional policy tool of the Federal Reserve (Fed) effectively hit the zero lower bound (ZLB) in December 2008 during the Great Recession. Consequently, the communication about the future path of the policy rate, i.e. forward guidance (FG), gained more importance although it had been an active policy tool since the Fed had started to issue detailed statements after Federal Open Market Committee (FOMC) announcements. Another unconventional monetary policy (UMP), large-scale asset purchases (LSAPs), was initiated in March 2009 to further stimulate the economy by lowering the long-term interest rates.

While the primary goal of these accommodative UMPs was to loosen the financial conditions to further stimulate the economy through promising lower medium to long term interest rates, newly emerging empirical studies document the surprising implications these accommodative policies had on private macroeconomic expectations (e.g. Nakamura and Steinsson (2018)). Campbell et al. (2012) coined the terms Delphic and Odyssean in reference to Homer's epic, Odyssey. A Delphic policy refers to the component of a policy announcement where the public learns the central bank's perception of the macroeconomic outlook while an Odyssean policy is the commitment of the central bank to a particular path for the policy rate, independent of future macroeconomic conditions. This theoretical decomposition of a central bank communication has crucial implications for monetary policy. If the central bank intends to stimulate the economy by committing itself to an interest rate path, the Delphic interpretation creates unintended consequences as macroeconomic expectations, such as inflation or growth, are adjusted downwards.

This paper first shows that both FG and LSAP surprises could be decomposed into Delphic and Odyssean components. This is a novel identification for the LSAP surprise. Thus, this paper argues that central bank communication of purchasing more assets than anticipated by market participants could either signal a "bad" macroeconomic outlook or looser financial conditions in the future by committing to lower long rates. In particular, the Delphic components of FG and LSAP surprises are identified as the fraction of a UMP, which is correlated with the difference between the Fed's and market participants' macroeconomic expectations, following a methodology similar to the one proposed by Campbell et al. (2017).

Then, this paper documents the plausibility of the proposed Delphic and Odyssean decomposition. In particular, the Delphic and the Odyssean components have the opposite impact on macroeconomic expectations of unemployment, growth and inflation in the US over various horizons, along with growth and inflation expectations in other advanced and large emerging market economies for the following year. Bauer and Swanson (2020) recently pointed out the relevance of macroeconomic news revealed before the FOMC announcements in understanding the response of macroeconomic expectations to monetary policy surprises. I conduct a robustness check on the sign and the significance of my results. I show that the economic and statistical significance of the Delphic components are robust to taking the most recent economic news revealed before the FOMC announcement into account.

Furthermore, I document the high frequency responses of US Treasury yields, the US dollar and the S&P 500 to Delphic and Odyssean components. While the yield curve and exchange rate are very responsive with the expected signs, the stock market is not responsive to UMPs during the ZLB period.[32] I also estimate the daily responses of the stock market and yield curve volatility measures, and corporate spreads. I find that the riskier bonds are more sensitive to Delphic policies.

Related Literature This paper is related to a number of different lines of literature. Following Kuttner (2001), the event study literature identified the conventional monetary policy surprise, the target surprise, as the change in the current month or one-month-ahead Fed funds futures rate. At the ZLB, the variation in this monetary policy surprise is clearly zero. Gürkaynak et al. (2005) extend this methodology by identifying a second significant

[32] Note that Jarocinski and Karadi (2020) disentangle the Delphic and Odyssean components of conventional monetary policy surprises, i.e. the 30-minute change in the 3-month Fed funds futures rate, using the 30-minute stock market response around FOMC announcements between 1990-2016.

monetary policy factor, the future path of the policy rate, in other words, FG. They further show that these two factors almost fully explain the movement of the term structure around FOMC announcements. After the initiation of the LSAPs, a new line of research that separates the surprise effects of different UMPs emerged. Rogers et al. (2018) and Swanson (2020) disentangle the effects of FG and LSAP surprises, extending the methodology in Gürkaynak et al. (2005) to the ZLB period. Swanson (2020) shows that FG and LSAP surprises almost fully explain the movement of the term structure around FOMC announcements during the ZLB. I use the approach in Rogers et al. (2018) to identify UMPs in the US.

An empirical body of research provides evidence that macroeconomic expectations might improve following a monetary policy tightening (or vice versa) to the contrary of what standard theory would suggest. Romer and Romer (2000) show that inflation expectations are adjusted in the opposite direction at certain time periods. This work is followed by Campbell et al. (2012) and Nakamura and Steinsson (2018) who document similar opposite responses of unemployment and growth expectations to FG communication, respectively. Coiobon et al. (2019) document how different forms of communication influence the inflation expectations of individuals empirically. They propose policy prescriptions for central banks about how to communicate to the public. For the same purpose, empirically decomposing an FG surprise into its Delphic and Odyssean components is essential for future policy actions.

Campbell et al. (2017) propose an empirical methodology to disentangle the Delphic component of an FG surprise. This method uses the difference between the Fed's and private macroeconomic expectations. Assuming that the Fed's perception of the macroeconomy is inferred by the FOMC announcement, which was particularly detailed in the last decade, Campbell et al. (2017) label the fraction of the FG surprise that is explained by the Fed's distinct perception of the macroeconomy, i.e. the deviation of their macro expectations from private expectations, the Delphic component. As one would expect in theory, they further show that private expectations respond to the Delphic component with an opposite sign (e.g. a Delphic easing lowers growth expectations). Similarly, Jarocinski and Karadi (2020) separate the information conveyed by the Fed into monetary policy and the Fed's assessment of the economic outlook. Andrade and Ferroni (2021) identify the Delphic and Odyssean components of FG communication in the Euro Area. In particular, they assume that an FG tightening has a Delphic component if it raises the slope of the term structure of interest rates and generates a positive variation in inflation expectations. I follow a methodology similar to the one suggested in Campbell et al. (2017).

Apart from the empirical identification of these components, there is a newly emerging line of theoretical literature that discusses whether the central banks should employ Odyssean or Delphic policies. Andrade et al. (2019) construct a structural framework in a standard New Keynesian model where agents have heterogenous beliefs with regards to the nature of an FG communication in a liquidity trap. They show a crucial FG trade-off between the optimism of those who believe the central bank can commit and the induced excess pessimism of non-believers. In related work, Barthelemy and Mengus (2016) argue that signaling Odyssean FG cannot take place after a liquidity trap begins. Bassetto (2019) discusses the cheap talk aspect of an FG communication. I document that a mixture of Delphic and Odyssean policies has opposing implications on macroeconomic expectations without taking a stance on the optimality of either policy.

The body of literature that documents the real and financial impacts of an FG surprise without segregating the Delphic and Odyssean components is vast. Campbell et al. (2019) show the limits of an FG shock in a structural model of imperfect communication. Bundick and Smith (2020) document the dynamic effects of an FG shock. In particular, they match the empirical effects of an FG shock, measured by a structural VAR, with the impulse responses implied by a standard model of nominal rigidity. The studies that employ a standard model of nominal rigidity introduce a discount framework to address the FG puzzle, i.e. the overestimation of the effects of an FG shock by a standard model.[33] The first chapter discusses how to model an FG shock and address the implied FG puzzle in detail.

The rest of this paper is organized as follows: Section 2 describes the identification of the Delphic and Odyssean components of UMP surprises. Section 3 presents the responses

[33] Other examples include: Del Negro et al. (2015) who introduce probability of dying, Gabaix (2020) who defines a discount parameter due to cognitive myopia, McKay et al. (2016) who employ uninsurable income shocks and borrowing constraints, Angeletos and Lian (2018) who remove common knowledge, Campbell et al. (2017) who introduce preferences for government bonds, Campbell and Weber (2018) who introduce imperfect credibility, and Farhi and Werning (2019) who employ bounded rationality and incomplete markets simultaneously.

of domestic and international private expectations. Section 4 discusses the response of asset prices to decomposed UMPs. Section 5 shows the robustness of the identified Delphic components to macroeconomic news revealed before the FOMC announcements. Section 6 concludes.

2.2 Delphic and Odyssean UMP Surprises

2.2.1 Identification of FG and LSAP Surprises in the ZLB Period

First, I identify FG and LSAP surprises following a similar methodology as in Rogers et al. (2018). I construct FG surprises as the 120-minute change (from 15 minutes before the FOMC announcement to 1 hour and 45 minutes after the announcement) in the 8th Eurodollar futures rate, i.e. the market expectations of what the short rates in the US will be roughly in two years.[34] I assume that term premia do not change over this small interval following the literature (e.g. Piazzesi and Swanson (2008), Cochrane and Piazzesi (2005), Evans and Marshall (1998)).[35] This factor is highly correlated (88%) with the path factor obtained through rotating the first two principle components of asset price movements as in

[34]The choice of Eurodollar futures to capture the interest rate expectations is due to the liquidity of these assets. Their high frequency response to FOMC announcements within a 120-minute window is highly volatile. One might argue that the interest rate expectations in the US are better captured by the OIS rates. However, the OIS futures are less volatile. In order to control for the difference between the interest rate implied by Eurodollar futures (the LIBOR rate) and the OIS rate, I check the daily response of the LIBOR-OIS spread to an FG surprise and find no economic significance. The spread moves a basis point in response to an FG surprise that moves the 8-quarter-ahead interest rate expectations by 25 basis points.

[35]I also find that the term premium component of the two year rates do not significantly move at daily frequency around FOMC announcements during the ZLB period.

Gürkaynak et al. (2005).[36] Note that the Fed funds futures rate, i.e. the market expectations of what the Fed funds rate will be at the end of the current month, and its surprises were practically zero during the ZLB period.

The asset price movements around FOMC announcements at the ZLB can be explained by the two principal components of the changes in interest rate expectations at different horizons as shown in Swanson (2020). These principal components can be rotated to have the structural interpretation of an FG and LSAP surprise. Following Rogers et al. (2018), I identify LSAP surprises using the high frequency change in the 10-year Treasury yields and the FG surprise since LSAP surprises target long rates directly while FG also influence long rates through changes in shorter term interest rate expectations. Formally, I regress the 120-minute change in the 10-year Treasury yields around FOMC announcements on the FG surprise and label the residuals as the LSAP surprise. Thus, the high frequency change in the 10-year Treasury yields is explained by the combination of FG and LSAP surprises by construction. Figure 10 shows the identified empirical FG and LSAP surprises during the ZLB period.

2.2.2 Extracting the Delphic Component of a UMP

Woodford (2012) and Campbell et al. (2012) discuss the ambiguous implications of com-

[36] I employ this method instead of rotating the first two principle components of asset price movements as in Gürkaynak et al. (2005) because of the ZLB during which the short-term interest rate expectations were very low. While the Gürkaynak et al. (2005) approach is linked to a combination of interest rates spanning various maturities, most of which were unusually low at the ZLB, this approach directly links the FG surprise to the two-year rate.

mitting to a lower interest rate in the near future for macroeconomic expectations. In particular, when a central bank is constrained by the ZLB, a communication that the policy rate will stay at the ZLB for longer than the public expected could either be interpreted as "bad news" about the macroeconomic outlook or "good news" as financial conditions will be looser for a longer period of time.

Campbell et al. (2012) define Delphic FG as the component of a monetary policy announcement where the public learns the macroeconomic expectations of the central bank and infers possible future policy actions. On the other hand, an Odyssean FG surprise is the commitment of the central bank to a particular path for the policy rate regardless of the future macroeconomic conditions. Formally, Campbell et al. (2017) identify the Delphic FG as the fraction of an FG surprise that is correlated with the difference between the macroeconomic expectations of the Federal Reserve and the market participants.

Similar to the ambiguous implications of the future path of the policy rate for macroeconomic expectations, a monetary policy announcement which is intended to lower long rates through asset purchases could have the same opposing impact on private expectations in principal. For instance, a larger than expected asset purchase could either be interpreted as "bad news" about the macroeconomic outlook or "good news" as long rates will be lower. Thus, I apply a methodology, which is similar to the one proposed by Campbell et al. (2017) to extract the Delphic component of an FG surprise, to identify the Delphic component of an LSAP surprise.

First, I take the difference between the Greenbook forecast and the most recent Bluechip forecast[37] of GDP growth and CPI inflation before every scheduled FOMC announcement from January 2008[38] to December 2014.[39] Unlike Campbell et al. (2017), I do not include unemployment forecasts due to the very high correlation between GDP growth and unemployment expectations. I consider the nowcast and the forecast for the next four quarters of GDP growth and CPI inflation due to the limit on the Bluechip forecast horizon. Thus, I create a dataset of 10 variables. Then, as in Gürkaynak et al. (2005), I take the short and the long factor of each macro variable forecast by taking their first two principal components and rotating them such that the short component moves one-to-one with the nowcast. Hence, my dataset of the differences between the Greenbook and Bluechip forecasts for the next year is reduced to four variables: the short and long factors of GDP growth and CPI inflation.

I regress both the LSAP surprise and the FG surprise as identified in Section 2.1 on these four factors, which show the difference between the Fed's and private agents' perception

[37]Following Campbell et al. (2017), I match a Greenbook forecast, which is dated a week before the FOMC announcement, with the most recent Bluechip forecast, which is published on the 10th of every month. If the Greenbook is dated on the 10th of a month, I match it with the Bluechip forecast of the same date.

[38]Scheduled FOMC meetings of 2008 are included in my sample since the target Fed funds rate surprises, i.e. 120-minute change in the current or one-quarter-ahead Fed funds futures rate around FOMC announcements, were very small (around 2.5 basis points on average in absolute magnitude).

[39]The dataset is not yet extended to October 2015, the end of the ZLB period, as the Greenbook data becomes available with a 5 year lag.

of the macroeconomic outlook, and their lags.[40]

$$UMP_t = \beta_0 + \beta_y^s y_t^s + \beta_y^l y_t^l + \beta_\pi^s \pi_t^s + \beta_\pi^l \pi_t^l + \beta_{y,-1}^s y_{t-1}^s + \beta_{y,-1}^l y_{t-1}^l + \beta_{\pi,-1}^s \pi_{t-1}^s + \beta_{\pi,-1}^l \pi_{t-1}^l + \varepsilon_t \tag{22}$$

where UMP_t is the LSAP surprise or FG surprise, y_t is the GDP factor and π_t is the CPI inflation factor. s superscript refers to the short factor while the l superscript is the long factor.

Table 5 shows the results of both regressions. I use the Bayesian information criterion (BIC) to select the model that best explains the UMPs. While the BIC selects the model with all four factors with their lags for the FG surprise, it chooses the model with only the long growth factor and its lag for the LSAP surprise. Given the best model for each UMP, I use the fitted values to identify the Delphic components. I conduct this analysis for the ZLB period with 56 observations.[41]

The main novelty of this identification is the decomposition of the LSAP surprise into its Delphic and Odyssean components. Besides, I employ BIC to pick the model that best describes the Delphic components. Since I can observe the difference between the Fed's and private macroeconomic expectations up to a year, I assume the difference between the two expectations is zero after a year.[42] Thus, I label the residuals of each regression as the

[40]Following Campbell et al. (2017), the lags are added since the Fed could be revealing its perception about the state of the economy with a lag.

[41]There are 8 scheduled FOMC announcements over 7 years.

[42]This assumption implies that there is no longer run Delphic component. The next section discusses the plausibility of this assumption.

Odyssean component, which is orthogonal to the Delphic component by construction.

Figures 11-12 plot the decomposed LSAP and FG surprises respectively. Delphic components of both policies are larger in absolute magnitude in the earlier years of the ZLB, when the uncertainty regarding the state of the economy was higher. As market participants learned more about the nature of the ZLB period, the difference between their and the Fed's macroeconomic expectations decreased, yielding smaller Delphic components for both policies.

The decomposed UMPs plotted in Figures 11-12 support the plausibility of the methodology. A clear example of a policy rate commitment was announced in August 2011 when the FOMC communicated that the policy rate will stay at the ZLB until mid-2013. Figure 11 shows that this FG communication is purely interpreted as an Odyssean FG surprise as one would expect. Likewise, Figure 12 illustrates that the initiation of the LSAP policies in March 2009 is mostly identified as a commitment to keeping long rates lower than the public expected. However, there is a Delphic component to this LSAP easing since this unconventional policy was being introduced for the first time, simultaneously implying "bad news" about the state of the economy.

2.3 Response of Expectations to Decomposed UMPs

2.3.1 Domestic Private Expectations

Table 6 shows the response of private macroeconomic expectations to FG and LSAP surprises, and their Delphic and Odyssean components. The first two columns report the baseline regressions in which the monthly changes in the Bluechip forecasts of unemployment, GDP growth and inflation around FOMC announcements are regressed on the UMPs in the US between January 2008 and December 2014.

$$\Delta BC_t^{h,i} = \beta_0^{h,i} + \beta_{FG}^{h,i} FG_t + \beta_{LSAP}^{h,i} LSAP_t + \varepsilon_t \tag{23}$$

where $\Delta BC_t^{h,i}$ is the monthly change in the Bluechip forecast of macro variable i for h quarters ahead, where $h \in \{0, 1, ..., 4\}$, around FOMC announcements. FG and LSAP surprises are as described in Section 2.1. $t \in T$ where $T = 56$, the number of FOMC announcements.

The following four columns report the results of the decomposed regressions in which the monthly Bluechip forecast changes are regressed on the Delphic and Odyssean components of FG and LSAP surprises.

$$\Delta BC_t^{h,i} = \beta_0^{h,i} + \beta_{DFG}^{h,i} DFG_t + \beta_{OFG}^{h,i} OFG_t + \beta_{DLSAP}^{h,i} DLSAP_t + \beta_{OLSAP}^{h,i} OLSAP_t + \varepsilon_t \tag{24}$$

where DFG and DLSAP stand for the Delphic components of FG and LSAP surprises respectively while OFG and OLSAP refer to the Odyssean components. All components are constructed as described in Section 2.2.

The hypothesis is that a Delphic easing, whether FG or LSAP, should increase unemployment expectations, and decrease growth and inflation expectations since it signals “bad” news about the macroeconomy. On the other hand, the Odyssean component should have the opposite sign as it signals that the financial conditions will be looser.

In the top panel, the baseline regressions show that the unemployment expectations respond to an FG surprise with a negative sign at shorter horizons.[43] Counterintuitively, this means that an FG easing increases the unemployment expectations in the US. These inverse signs are consistent with the findings of Campbell et al. (2017) who were motivated by these findings and hypothesized that the inverse sign should be due to the Delphic component of an FG surprise. The next four columns show the results of the decomposed regression. As expected, the inverse sign of an FG surprise is due to the Delphic component of an FG surprise. Moreover, the estimated impact of a Delphic FG surprise on unemployment expectations is economically significant. The Delphic component of an FG easing[44] increases the current and one-quarter-ahead unemployment expectations by around 50 basis points (bps) during the ZLB period.

As for the LSAP surprise, the baseline regression of unemployment expectations does

[43] These results are marginally insignificant at 10%.

[44] The unit of FG surprises is standardized to a 25 basis point change in 2-year-ahead interest rate expectations in the US around FOMC announcements. Note that the average size an FG surprise plotted in Figure 10 is 22 basis points in absolute value.

not yield any significant coefficients. However, the decomposed regression shows that the Delphic components of an LSAP easing, which signals bad news about the macroeconomy, also increases the unemployment expectations at all horizons with one standard error significance. Thus, while the estimated coefficients of the Delphic FG are similar to the findings of Campbell et al. (2017), the marginal significance of the Delphic LSAP coefficients with the expected sign is a complementary finding which supports the hypothesis of extending the Delphic interpretation of a monetary policy surprise to LSAPs. Moreover, over longer horizons, an Odyssean LSAP easing lowers the unemployment expectations. This finding is consistent with the assumption that the residuals of Equation (22) mostly contain information about Odyssean FG rather than longer-run Delphic FG.

The findings in the other two panels of Table 6 are also consistent with the expected signs of the Delphic and Odyssean components of UMPs. The statistically significant coefficients are also economically significant. The baseline regressions of both growth and inflation expectations on any horizon report an expected sign, i.e. an easing policy increases growth and inflation expectations. Moreover, the estimated impact of UMPs on growth and inflation expectations during the ZLB period are large. While an LSAP easing[45] increases the growth expectations of the current quarter by around 1.5 percentage points, the same LSAP surprise increases the inflation expectations of next quarter by about half a percentage point. The relatively smaller influence on inflation expectations is consistent with the

[45]Similarly, the unit of LSAP surprises is standardized to a 25 basis point change in the 10-year interest rate expectations in the US around FOMC announcements.

well-anchored inflation expectations in the US.

The decomposed regressions show that the conventional signs reported in the baseline regressions operate through the Odyssean component of FG and LSAP policies.[46] In particular, the positive impact of an LSAP easing on growth and inflation expectations are significant over various horizons. All of these coefficients are due to the Odyssean component of an LSAP surprise. Likewise, an FG easing is associated with an increase in inflation expectations at shorter horizons, which is explained by the Odyssean component.[47]

2.3.2 Foreign Private Expectations

The Bluechip economic indicators report growth and inflation expectations in some advanced and large emerging market foreign economies for the following year. I conduct the same regression analysis described in Equations (23)-(24) for this dataset. Table 7 shows that the responses of growth and inflation expectations for the Eurozone, the U.K., Japan, Canada, China and Brazil are also consistent with the expected signs of the Delphic and Odyssean components of FG and LSAP surprises. This is a novel finding in this line of literature. Besides, the magnitudes of the estimated coefficients suggest that the markets expected significant spillovers of the US UMPs to other advanced and large emerging market economies. The responses of growth and inflation expectations to the US UMPs

[46] Campbell et al. (2017) report only one significant coefficient in their baseline regressions for growth expectations and three significant Delphic FG coefficients with the expected signs. They do not report significant findings for the response of inflation expectations.

[47] Although the Delphic LSAP surprise is significant with the wrong sign for a quarter ahead inflation expectations, the Odyssean components of that regression are also significant with the correct signs.

are mostly homogenous across these six countries both under baseline and decomposed regressions.

A Delphic interpretation of a UMP easing in the US is expected to lower growth and inflation expectations in other advanced and emerging market economies unambiguously since it signals "bad" news about the US economy, and thus the global economic outlook. On the other hand, an Odyssean interpretation of a UMP easing in the US could imply higher or lower growth for other advanced and emerging market economies. While the looser financial conditions could help economic activity, a depreciated dollar against the local currency can hurt the competitiveness of domestic goods against the US goods. However, foreign central banks often respond to lower competitiveness caused by the depreciated dollar through lowering their policy rates.[48] The responsiveness of foreign central banks to US monetary policy is consistent with the empirical documentation of the global financial cycle induced by the US monetary policy in Miranda-Agrippino and Rey (2019). The results in Table 7 indicate that an Odyssean UMP in the US is interpreted as "good" news in other advanced and large emerging market economies.

An important finding in the baseline regressions is that the FG surprise influence the growth and inflation expectations with the expected sign, i.e. an easing increases the expectations. Thus, when the Fed communicates that the policy rate will remain at the ZLB for longer than market participants expected, it is interpreted as "good" news about the

[48] If the foreign economy is constrained by the ZLB, the foreign central bank can undertake a UMP easing.

global economic outlook. Due to Fed's commitment to looser financial conditions for a longer time period, market participants are optimistic about the growth prospects in the upcoming year. While an FG easing significantly increases growth and inflation expectations in China, it also increases inflation expectations in Canada and growth expectations in Brazil at a 10% significance level. All growth expectations increase in response to an FG easing at one standard error significance.

On the other hand, an LSAP easing decreases growth and inflation expectations in other advanced and large emerging market economies. Thus, the asset purchase program is interpreted as a negative signal about the current state of the US economy, and thus the global economy. While the growth expectations of Brazil are adjusted downwards very significantly following an LSAP easing, the inflation expectations are also decreased significantly in the Eurozone, the UK, Canada and China. Decomposed regressions show that these inverse signs are due to the Delphic LSAP surprises. Moreover, the negative impact of a Delphic LSAP easing is much stronger on the growth expectations of the foreign economies in the sample. For instance, the Delphic component of an LSAP easing decreases the growth expectations more than a percentage point in the UK and around 80 bps in the Eurozone.

The decomposed regression results show that the Delphic and the Odyssean components of FG and LSAP surprises have the expected signs. The expectation increasing impact of an FG surprise is due to the Odyssean component of an FG surprise.[49] Likewise, the expectation lowering impact of an LSAP easing is very significantly explained by the Delphic LSAP surprise for all countries in the sample. Furthermore, the estimated impact of the Delphic LSAP surprise is economically large on growth expectations in other advanced and large emerging market economies.

2.4 Response of Asset Prices to Decomposed UMPs

In this section, I present the responses of asset prices in the US to the Delphic and Odyssean components of the FG and LSAP surprises. In particular, I present the high frequency response of the US Treasury yields with maturities ranging from 3 months to 30 years, 5 and 10-year TIPS yields, the stock market index, and the EUR/USD exchange rate. Moreover, I report the daily responses of corporate yields and spreads of firms with different investment grade ratings.

The baseline regressions are estimated as:

$$\Delta AP_t = \beta_0 + \beta_{FG} FG_t + \beta_{LSAP} LSAP_t + \varepsilon_t \tag{25}$$

where ΔAP_t is the change in the given asset price around FOMC announcements. FG and LSAP surprises are as described in Section 2.1. $t \in T$ where $T = 56$, the number of FOMC

[49]The results are only insignificant for Japan.

announcements. The decomposed regressions are estimated as:

$$\Delta AP_t = \beta_0 + \beta_{DFG} DFG_t + \beta_{OFG} OFG_t + \beta_{DLSAP} DLSAP_t + \beta_{OLSAP} OLSAP_t + \varepsilon_t \tag{26}$$

where DFG and DLSAP stand for the Delphic components of FG and LSAP surprises respectively while OFG and OLSAP refer to the Odyssean components. All components are constructed as described in Section 2.2.

2.4.1 Response of the Yield Curve

Table 8 reports the response of the yield curve to the UMPs. The baseline regression shows that both the FG and LSAP surprises very significantly impact the risk-free rates at different maturities. Not surprisingly, the FG surprise is more effective in moving the short to medium term maturities while the LSAP surprise is more effective at longer maturities. Likewise, both UMPs are effective in moving the TIPS rates at 5 and 10 year horizons.

While both UMPs are moving the yield curve in the expected direction, i.e. an easing lowers the risk-free rates while a tightening increases them, I do not argue for a particular distinction between the Delphic and the Odyssean channels of these policies. Consistent with this prior, the decomposed regression results presented in the next four columns show that two components always have the same sign and their magnitudes are not statistically different from each other. Thus, UMPs influence the yield curve due to both components, neither of which is more influential than the other.

2.4.2 Response of Stock Prices and the US Dollar

Table 9 presents the high frequency response of the S&P 500 index and the EURUSD exchange rate, the US dollar value of a Euro, around the FOMC announcements. The 120-minute response (from 15 minutes before the announcement to 1 hour and 45 minutes after the announcement) of the stock market index does not significantly respond to UMPs, and their Delphic and Odyssean components. On the other hand, the baseline regression of the US dollar shows that half of the variation in the EURUSD exchange rate in a two-hour window around an FOMC announcement is explained by the two UMPs. Thus, the systematic relationship between the UMPs and the exchange rate is higher than the one between the UMPs and stock prices. The direction of this relationship is as expected; an easing depreciates the USD. The EURUSD exchange rate moves almost a percentage point in response to an FG or LSAP easing.

In theory, the direction of the impact of Delphic and Odyssean components on the exchange rate should be the same. While a Delphic easing, signaling "bad" economic conditions in the US, should depreciate its currency through lower international demand for US financial securities, an Odyssean easing, signaling commitment to lower interest rates in the US, should also depreciate the currency for the same reason. The decomposed regression results are consistent with this prior. Moreover, the estimated impact of Delphic FG is larger than that of Odyssean FG as expected. However, the difference between these estimated coefficients are not statistically significant.

2.4.3 Response of Volatility Measures

Table 10 illustrates the responses of volatility measures of the stock market and the yield curve to UMPs along with their Delphic and Odyssean components. I employ the Volatility Index (VIX) of the Chicago Board Options Exchange, which is derived from the options implied volatility of the S&P 500 index, and the Merrill Lynch Options Estimate (MOVE) index, which is based on the options implied volatility of US Treasury yields of various maturities. The regressions present the daily responses of the VIX and MOVE.

The results point out a striking difference between the impact of FG and LSAP policies on the volatility measures which reflect the uncertainty associated with the stock market and yield curve. Both baseline regressions suggest that FG and LSAP surprises have the opposite impact on the uncertainty measures.[50] While an FG easing decreases the stock market and yield curve uncertainty, an LSAP easing increases both uncertainty measures. The decomposed regressions show that both channels operate through commitment to lower rates, i.e. the Odyssean components. The volatility decreasing impact of an Odyssean FG easing is consistent with the findings of Bekaert et al. (2013), who find that a lax conventional monetary policy decreases the volatility implied by the VIX. Thus, the uncertainty increasing impact of an Odyssean LSAP easing is a distinct result compared to conventional policies and the FG. This could be due to the uncertainty associated with the introduction of LSAPs as a novel policy tool.

[50] The impact of LSAPs on the MOVE index is significant at 20%.

2.4.4 Response of Corporate Yields and Spreads

Table 11 shows the response of corporate yields and spreads of firms with different investment grades, namely AAA, BAA and BBB. Since both FG and LSAP surprises decrease the risk-free rates at different horizons, the corporate yields also go down as shown in the first three lines of the baseline regressions. This decrease in the corporate yields are not particularly due to the Delphic or the Odyssean components. The decomposed regression results show that yields at different investment grade ratings are affected by the Delphic and Odyssean components similarly.

A more interesting exercise is to assess the corporate spread responses of firms with different risk levels. Baseline regressions show that a UMP easing increases the spread between the risky and risk-free bonds. Thus, a UMP easing decreases the risky yields less than the risk-free yields. There are two main mechanisms through which this could be true. The first channel is mechanical: since the Fed is operating its LSAP policies mostly through the 10-year Treasury bonds, it impacts the yields of these bonds more than other type of bonds. Alternatively, the risk associated with the corporate bonds might be going up, especially for low investment grade bonds.

The decomposed regressions are consistent with both mechanisms as the Delphic and Odyssean components are both significant with a negative sign. However, the magnitude of their impact varies across bond spreads with different levels of risk. The riskier bond spreads are more sensitive to the Delphic component of an LSAP surprise since these bonds are more sensitive to aggregate risks. In particular, the absolute magnitude of the impact of a Delphic LSAP surprise is statistically larger than the impact of the Odyssean component for BBB-10Y spreads.[51] Similarly, the safer bond spreads are more responsive to Odyssean FG surprises. The size of the impact of an Odyssean FG surprise is statistically larger than the impact of a Delphic FG for AAA-10Y spreads.[52]

2.5 Robustness Check: News Announcements

A recent concern on the existence of a Delphic FG is proposed by Bauer and Swanson (2020) who build their argument on the availability of new public information about the state of the economy between the Bluechip forecast and the FOMC announcement dates. They argue that if market participants *systematically underestimate* (in absolute magnitude) the Fed's response to this new public information, the opposite relationship between private macroeconomic expectations and monetary policy surprises is explained. However, this argument is valid only if market participants systematically underestimate the Fed's response to news on average.

To empirically support their argument, Bauer and Swanson (2020) cite a finding from earlier work: prior economic news are correlated with upcoming monetary policy sur-

[51]Note that there is no statistical difference between the impact of Delphic and Odyssean components of LSAP surprises on safer bond spreads.

[52]The only exception to these set of results is reported in the decomposed regression for BBB-10Y spreads: The magnitude of the impact of an Odyssean FG is larger than that of a Delphic FG. However, the statistical significance of the difference between these two coefficients is weaker.

prises.[53] Since economic news also influence private expectations, Bauer and Swanson (2020) point out a possible omitted variable bias problem. After adding an economic news variable, which captures information about the macroeconomy before the FOMC announcement, as a control variable, they conclude that the opposite relationship between private expectations and the policy surprise disappears. However, the implications of the relationship between private expectations and policy surprises (a baseline regression) are not conclusive since Delphic and Odyssean components could be canceling each other out (or one component could be dominating the another).

As a robustness check, I include the most recent non-farm payrolls, industrial production and CPI inflation news surprises (the difference between the actual release and survey expectations) announced before the FOMC announcements as control variables in the regressions presented in Table 6. Table 12 shows the responses of private expectations to monetary policy surprises in the presence of macroeconomic news surprises as control variables. The results show that both the significance and the magnitude of the estimated coefficients are robust to adding macroeconomic news surprises as control variables.

Following the empirical methodology described in Section 2 provides a direct evidence on the presence of a Delphic component for both FG and LSAP policies in the US. The argument presented by Bauer and Swanson (2020) is built on the assumption that the Fed

[53] Miranda-Agrippino (2017) explains this by a risk premium required by investors to compensate themselves for the interest rate risk around FOMC announcements while Cieslak (2018) interprets this as the lack of full information regarding Fed's reaction function. The authors follow the latter explanation.

and the market participants have the same information set about the macroeconomy (but market participants underestimate Fed's reaction function). However, I first extract the difference between the ex-ante macroeconomic expectations of market participants and the Fed. Then, I show that this difference is correlated with the upcoming UMPs, and the opposite relationship between private macroeconomic expectations and monetary policy surprises is explained by the fraction of UMPs that is correlated with the difference in expectations.

2.6 Conclusion

I decompose FG and LSAP surprises into their Delphic and Odyssean components. This is a novel identification for the LSAP surprise. While the Delphic components convey information about the Fed's perception of the current and the future states of the macroeconomy, the Odyssean components inform agents about the additional commitment the central bank makes to keep the medium and long rates low for a longer period of time. I identify the Delphic component of a UMP surprise as its fraction which is correlated with the difference between the Fed's and market participants' macroeconomic expectations.

I show that the Delphic and Odyssean components of FG and LSAP surprises have the opposite impact on macroeconomic expectations of unemployment, growth and inflation during the ZLB period in the US over various horizons. Besides, they also have the opposite impact on the growth and inflation expectations of the following year in other advanced and large emerging market economies. Moreover, I document the high frequency responses of the yield curve, the US dollar and the stock market to the Delphic and Odyssean components. While the first two respond very significantly with the expected signs, I find that the stock market is not responsive to UMPs. Lastly, I study the daily responses of volatility measures and corporate spreads, and find riskier bonds to be more sensitive to Delphic policies.

Table 5: Interaction of UMPs with the Fed's Different View of the Macroeconomy

	LSAP	FG
Growth Short Factor	0.02	0.15**
	(0.04)	(0.06)
Growth Long Factor	0.15**	-0.01
	(0.07)	(0.09)
Inflation Short Factor	-0.03	0.01
	(0.03)	(0.05)
Inflation Long Factor	0.03	−0.15
	(0.06)	(0.09)
Growth Short Factor Lag	-0.01	0.05
	(0.04)	(0.06)
Growth Long Factor Lag	−0.11*	0.01
	(0.06)	(0.08)
Inflation Short Factor Lag	0.01	-0.003
	(0.02)	(0.05)
Inflation Long Factor Lag	0.001	0.20**
	(0.05)	(0.09)
Constant	-0.01	0.001
	(0.03)	(0.05)
N	56	56
R^2	0.29	0.18

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The LSAP and FG surprises are identified as described in Section 2.1. The long and short factors are constructed as described in Section 2.2.

Table 6: Response of Bluechip Forecasts to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
Unemployment								
Nowcast	-0.21	-0.17	0.1	-0.49**	-0.14	-0.52	-0.04	0.16
	(0.14)	(0.28)		(0.23)	(0.12)	(0.36)	(0.25)	
Q1	-0.2	-0.13	0.08	-0.49**	-0.13	-0.55	0.03	0.17
	(0.14)	(0.27)		(0.2)	(0.13)	(0.34)	(0.24)	
Q2	-0.15	0	0.04	-0.4*	-0.09	-0.44	0.17	0.12
	(0.14)	(0.26)		(0.22)	(0.13)	(0.35)	(0.24)	
Q3	-0.12	0.07	0.03	-0.44**	-0.05	-0.5	0.29	0.17
	(0.13)	(0.22)		(0.18)	(0.12)	(0.34)	(0.21)	
Q4	-0.07	0.11	0.02	-0.32*	-0.02	-0.51	0.35	0.16
	(0.14)	(0.22)		(0.18)	(0.13)	(0.36)	(0.21)	
Growth								
Nowcast	-0.45	-1.47**	0.16	-0.22	-0.5	-1.2	-1.57*	0.16
	(0.39)	(0.71)		(0.7)	(0.41)	(1.36)	(0.82)	
Q1	-0.26	-1.1**	0.17	-0.21	-0.27	-0.53	-1.32**	0.18
	(0.36)	(0.53)		(0.65)	(0.32)	(1.09)	(0.6)	
Q2	-0.41	-0.25	0.17	-0.43	-0.4*	0.46	-0.52	0.24
	(0.26)	(0.28)		(0.5)	(0.22)	(0.55)	(0.34)	
Q3	-0.21	-0.14	0.11	-0.31	-0.19	0.15	-0.26	0.14
	(0.18)	(0.14)		(0.31)	(0.15)	(0.32)	(0.19)	
Q4	-0.1	-0.19*	0.09	-0.23	-0.08	0.03	-0.27**	0.13
	(0.13)	(0.1)		(0.23)	(0.11)	(0.26)	(0.13)	
Inflation								
Nowcast	-1.46*	-0.99	0.2	-1.42	-1.46*	0.85	-1.7**	0.24
	(0.74)	(0.65)		(0.96)	(0.74)	(1.26)	(0.79)	
Q1	-0.47**	-0.46**	0.27	-0.85**	-0.38**	0.39	-0.8***	0.4
	(0.21)	(0.19)		(0.34)	(0.15)	(0.42)	(0.25)	
Q2	-0.16	0.1	0.08	-0.27	-0.13	0.02	0.13	0.09
	(0.11)	(0.16)		(0.22)	(0.12)	(0.25)	(0.16)	
Q3	0.03	-0.34***	0.15	0.14	0	-0.24	-0.38***	0.16
	(0.07)	(0.12)		(0.13)	(0.08)	(0.24)	(0.14)	
Q4	-0.06	-0.13**	0.09	-0.18	-0.04	-0.15	-0.12**	0.12
	(0.04)	(0.05)		(0.12)	(0.05)	(0.11)	(0.06)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the monthly updates of Bluechip forecasts around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 7: Response of International Forecasts for the Following Year to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
Eurozone								
Growth	-0.36	0.36	0.16	-0.32	-0.37*	0.81**	0.18	0.19
	(0.26)	(0.22)		(0.53)	(0.22)	(0.33)	(0.22)	
Inflation	-0.04	0.15**	0.07	0	-0.05	0.28*	0.1	0.1
	(0.04)	(0.06)		(0.1)	(0.04)	(0.16)	(0.08)	
United Kingdom								
Growth	-0.45	0.21	0.16	-0.48	-0.44*	1.15**	-0.15	0.25
	(0.32)	(0.29)		(0.65)	(0.24)	(0.43)	(0.23)	
Inflation	-0.06	0.16**	0.06	-0.14	-0.05	0.26*	0.12	0.07
	(0.06)	(0.08)		(0.17)	(0.06)	(0.15)	(0.09)	
Japan								
Growth	-0.33	0.27	0.15	-0.76	-0.23	0.84**	0.05	0.26
	(0.25)	(0.22)		(0.47)	(0.18)	(0.34)	(0.2)	
Inflation	0.05	0.09	0.01	0.11	0.03	0.19	0.05	0.02
	(0.06)	(0.15)		(0.18)	(0.07)	(0.22)	(0.18)	
Canada								
Growth	-0.43	0.27	0.19	-0.54	-0.4*	0.91***	0.02	0.25
	(0.3)	(0.19)		(0.57)	(0.23)	(0.33)	(0.18)	
Inflation	-0.14*	0.4*	0.23	-0.08	-0.15*	0.58**	0.33	0.25
	(0.08)	(0.2)		(0.16)	(0.09)	(0.27)	(0.2)	
China								
Growth	-0.18**	0.17	0.11	-0.25	-0.16*	0.65*	-0.01	0.2
	(0.07)	(0.11)		(0.21)	(0.08)	(0.34)	(0.17)	
Inflation	-0.27**	0.24**	0.14	-0.27	-0.27**	0.54	0.12	0.15
	(0.11)	(0.11)		(0.27)	(0.1)	(0.45)	(0.19)	
Brazil								
Growth	-0.34*	0.45***	0.23	-0.44	-0.31**	1.01***	0.24	0.29
	(0.18)	(0.16)		(0.35)	(0.14)	(0.27)	(0.16)	
Inflation	-0.72	6.4	0.04	-7.35	0.74	1.52	8.24	0.09
	(1.31)	(6.75)		(7.53)	(1.17)	(4.07)	(8.13)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the monthly updates of Bluechip forecasts around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 8: Response of the US Treasury Yields and TIPS to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
3-Month	0.01	0	0.05	0.02	0.01	0	0	0.06
	(0.01)	(0.01)		(0.02)	(0.01)	(0.03)	(0.01)	
6-Month	0.04**	0	0.27	0.08***	0.03**	-0.03	0.01	0.33
	(0.02)	(0.01)		(0.02)	(0.02)	(0.03)	(0.01)	
2-Year	0.14***	0.02	0.75	0.17***	0.13***	0.01	0.03	0.77
	(0.02)	(0.02)		(0.02)	(0.02)	(0.03)	(0.02)	
5-Year	0.23***	0.16***	0.96	0.22***	0.23***	0.16***	0.16***	0.96
	(0.01)	(0.02)		(0.01)	(0.01)	(0.03)	(0.02)	
10-Year	0.18***	0.25***	1	0.17***	0.18***	0.26***	0.25***	1
	(0.002)	(0.002)		(0.004)	(0.002)	(0.005)	(0.003)	
30-Year	0.09***	0.21***	0.73	0.08**	0.09***	0.2***	0.22***	0.73
	(0.02)	(0.06)		(0.03)	(0.02)	(0.07)	(0.05)	
TIPS 5-Year	0.21***	0.16***	0.94	0.18***	0.22***	0.16***	0.15***	0.94
	(0.02)	(0.04)		(0.02)	(0.02)	(0.05)	(0.04)	
TIPS 10-Year	0.17***	0.26***	0.94	0.16***	0.18***	0.26***	0.26***	0.94
	(0.01)	(0.02)		(0.02)	(0.02)	(0.03)	(0.02)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the 120-minute changes around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 9: Response of Stock Prices and the USD to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
SPX	-0.35	-0.94	0.11	-0.74	-0.26	-0.56	-1.09	0.13
	(0.45)	(0.78)		(0.58)	(0.48)	(1.01)	(0.86)	
EURUSD	-0.94***	-0.86**	0.5	-1.2***	-0.89***	-0.87*	-0.86**	0.51
	(0.21)	(0.39)		(0.3)	(0.23)	(0.5)	(0.42)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the 120-minute changes around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 10: Response of Volatility Measures to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
VIX	2.84*	-4.02**	0.29	2.11	3.03*	-1.65	-4.93**	0.32
	(1.55)	(1.5)		(1.57)	(1.63)	(3.55)	(2.14)	
MOVE	6.67***	-4.27	0.2	8.38	6.33**	3.4	-7.22*	0.23
	(2.37)	(3.29)		(5.02)	(2.37)	(7.85)	(4.3)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the daily changes around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 11: Response of Corporate Yields and Spreads to Decomposed UMPs

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
AAA	0.09***	0.2***	0.55	0.13***	0.08***	0.2***	0.21***	0.56
	(0.02)	(0.03)		(0.05)	(0.02)	(0.04)	(0.03)	
BAA	0.09***	0.23***	0.61	0.12**	0.09***	0.22***	0.23***	0.61
	(0.02)	(0.04)		(0.05)	(0.02)	(0.06)	(0.04)	
BBB	0.14***	0.19***	0.75	0.15***	0.14***	0.15***	0.21***	0.76
	(0.01)	(0.03)		(0.03)	(0.01)	(0.05)	(0.03)	
AAA-10Y	-0.1***	-0.1**	0.5	-0.04	-0.12***	-0.12*	-0.09**	0.54
	(0.02)	(0.04)		(0.04)	(0.02)	(0.07)	(0.04)	
BAA-10Y	-0.1***	-0.08	0.47	-0.05	-0.11***	-0.1	-0.07	0.49
	(0.02)	(0.06)		(0.04)	(0.02)	(0.08)	(0.06)	
BBB-10Y	-0.05**	-0.11***	0.36	-0.02	-0.06**	-0.17***	-0.09***	0.4
	(0.02)	(0.02)		(0.02)	(0.03)	(0.03)	(0.03)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the daily changes around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2.

Table 12: Response of Bluechip Forecasts to Decomposed UMPs and Economic News

	Baseline Regressions			Decomposed Regressions				
	FG	LSAP	R^2	DFG	OFG	DLSAP	OLSAP	R^2
Unemployment								
Nowcast	-0.25*	-0.21	0.16	-0.53**	-0.18	-0.4	-0.13	0.2
	(0.14)	(0.25)		(0.21)	(0.13)	(0.35)	(0.27)	
Q1	-0.25**	-0.16	0.17	-0.5***	-0.18	-0.46	-0.04	0.22
	(0.12)	(0.24)		(0.18)	(0.12)	(0.33)	(0.26)	
Q2	-0.22*	-0.03	0.2	-0.38**	-0.17	-0.32	0.1	0.24
	(0.12)	(0.23)		(0.18)	(0.12)	(0.32)	(0.24)	
Q3	-0.2**	0.03	0.27	-0.44***	-0.13	-0.38	0.2	0.33
	(0.1)	(0.17)		(0.17)	(0.1)	(0.27)	(0.2)	
Q4	-0.16	0.06	0.25	-0.32*	-0.1	-0.36	0.24	0.3
	(0.11)	(0.16)		(0.17)	(0.11)	(0.28)	(0.2)	
Growth								
Nowcast	-0.25	-1.43*	0.38	-0.37	-0.22	-1.46	-1.41*	0.39
	(0.4)	(0.78)		(0.7)	(0.43)	(1.19)	(0.84)	
Q1	-0.16	-1.06*	0.3	-0.1	-0.19	-0.46	-1.31*	0.31
	(0.35)	(0.61)		(0.6)	(0.35)	(0.98)	(0.66)	
Q2	-0.35	-0.21	0.22	-0.39	-0.37	0.47	-0.51	0.28
	(0.26)	(0.33)		(0.46)	(0.25)	(0.55)	(0.37)	
Q3	-0.16	-0.1	0.2	-0.23	-0.15	0.08	-0.18	0.21
	(0.17)	(0.17)		(0.26)	(0.16)	(0.3)	(0.21)	
Q4	-0.07	-0.16	0.2	-0.14	-0.07	0	-0.23	0.21
	(0.11)	(0.11)		(0.18)	(0.11)	(0.24)	(0.14)	
Inflation								
Nowcast	-1.09*	-0.76	0.35	-1.11	-1.13*	0.34	-1.23	0.37
	(0.63)	(0.82)		(0.84)	(0.66)	(1.37)	(0.93)	
Q1	-0.4**	-0.41*	0.34	-0.84**	-0.33**	0.24	-0.69**	0.42
	(0.19)	(0.23)		(0.33)	(0.16)	(0.4)	(0.28)	
Q2	-0.11	0.13	0.22	-0.21	-0.07	-0.06	0.21	0.24
	(0.09)	(0.12)		(0.21)	(0.1)	(0.24)	(0.15)	
Q3	0.03	-0.35***	0.15	0.14	-0.01	-0.21	-0.4***	0.17
	(0.07)	(0.12)		(0.15)	(0.07)	(0.26)	(0.14)	
Q4	-0.05	-0.12**	0.1	-0.18	-0.02	-0.19	-0.1	0.13
	(0.04)	(0.05)		(0.12)	(0.05)	(0.13)	(0.06)	

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The sample size spans all scheduled FOMC announcements between January 2008 and December 2014. The dependent variables are the monthly updates of Bluechip forecasts around FOMC announcements. The LSAP and FG surprises are identified as described in Section 2.1. The Delphic and Odyssean components are constructed as described in Section 2.2. The coefficients of economics news are not reported.

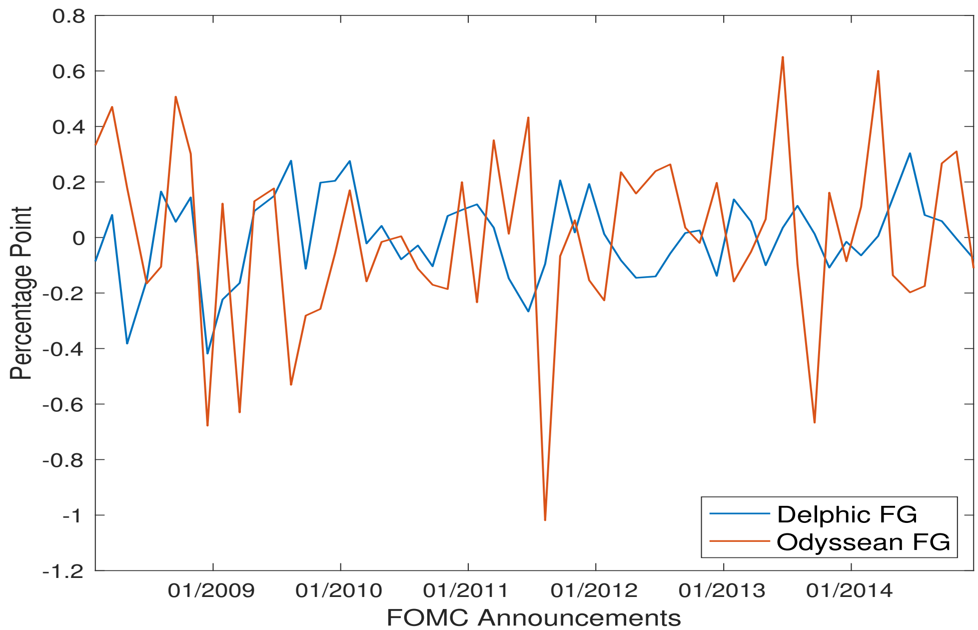
Figure 10: Empirical FG and LSAP Surprises during the ZLB Period

Notes: The blue line shows the FG surprise while the red line depicts the LSAP surprise for each scheduled FOMC announcement during the ZLB period. The empirical identification methodology is as described in Section 2.1. An FG surprise moves the 2-year interest rate expectations while an LSAP surprise moves the 10-year rate by the percentage point given on the vertical axis.

Figure 11: Decomposed LSAP Surprises during the ZLB Period

Notes: The blue line shows the Delphic LSAP surprise while the red line depicts the Odyssean LSAP surprise for each scheduled FOMC announcement during the ZLB period. The decomposition methodology is as described in Section 2.2.

Figure 12: Decomposed FG Surprises during the ZLB Period



Notes: The blue line shows the Delphic FG surprise while the red line depicts the Odyssean FG surprise for each scheduled FOMC announcement during the ZLB period. The decomposition methodology is as described in Section 2.2.

Chapter 3

3 Identification of Forward Guidance and QE Surprises in the UK

3.1 Introduction

Following the global financial crisis, the Bank of England (BoE) has lowered its policy rate, the Bank rate, to its effective lower bound (ELB) in March 2009.[54] While the Bank rate remained at its ELB for almost a decade, the BoE employed unconventional monetary policies (UMPs) to further stimulate the economy. In particular, the BoE initiated its quantitative easing (QE) program[55] on the same day the Bank rate hit its ELB. While the communication about the future path of the policy rate, i.e. forward guidance (FG), was an important monetary policy tool before the global financial crisis, it gained more importance as the Bank rate was constrained by the ELB.

Following Kuttner (2001), the event-study literature identified the conventional monetary policy surprise as the change in the current month or one-month-ahead Fed funds futures rate. At the ELB, the variation in this monetary policy surprise is clearly zero.

[54] Although the Bank rate was lowered to 0.1% in 2020, 0.5% was communicated as the ELB after the global financial crisis of 2008.

[55] While the Federal Reserve refers to this UMP as large-scale asset purchases (LSAPs), the BoE calls it QE policy.

Gürkaynak et al. (2005) extend this methodology by identifying a second significant monetary policy factor, i.e. the future path of the policy rate, in other words, FG. They further show that these two factors almost fully explain the movement of the term structure around Federal Open Market Committee (FOMC) announcements.[56] After the initiation of large-scale asset purchases (LSAPs) in the US, a new line of research that separates the surprise effects of different UMPs emerged. Swanson (2020) disentangles the effects of FG and LSAP surprises, extending the methodology in Gürkaynak et al. (2005) to the ELB period. Swanson (2020) shows that FG and LSAP surprises almost fully explain the movement of the term structure around FOMC announcements during the ELB period.

Using high-frequency data, I separately identify FG and QE surprises of the BoE during the ELB period in the UK, following the methodology of Swanson (2020). Then, I show the effects of these UMPs on asset prices in the UK and compare these effects with those in the US. I first document the response of gilt yields and term premia to these UMPs. Both surprises combined account for only a third of the daily variations in gilt yields and their term premia on the Monetary Policy Committee (MPC) announcement days during the ELB period. Besides, the impact of UMPs on gilt yeilds and term premia dies out within a few months. I also measure the responsiveness of stock prices, their volatility and the British pound to UMPs. While both UMP easings depreciate the pound, FG easings move stock prices up and their volatility down. QE surprises, on the other hand, do not

[56] Note that this is also true in the UK.

significantly move the stock price index and its volatility. Moreover, the impact of FG on the British pound persists for at least six months. Lastly, I illustrate that corporate bond spreads and equity risk premia increase in response to larger than expected asset purchases.

Related Literature Over the past decade, a body of research that measures the effectiveness of newly implemented LSAP policies in lowering the yield curve at the ELB has emerged. While Gagnon et al. (2011), Vissing-Jorgensen and Krishnamurthy (2011) and D'Amico and King (2013) show that the LSAP policies of the Federal Reserve were effective in flattening the yield curve, Joyce et al. (2011) come to the same conclusion for the UK. Given the effectiveness of the QE policies in the UK, there is a subsequent line of literature that empirically measures the impact of the QE policies employed by the BoE on macroeconomic variables. Bridges and Thomas (2012), Kapetanios et al. (2012), Baumeister and Benati (2013) and Churm et al. (2015) use VAR analyses to measure the real impact of the QE policies and report that the policies were significant in avoiding deflation and output losses.

There is parallel line of literature that empirically assesses the effects of QE policies in the UK on asset prices. Rogers et al. (2014) employ identification through heteroskedasticity to show that a QE surprise in the UK lowers government and corporate bond yields at maturities higher than 2 years. Christensen and Rudebusch (2012) use an empirical dynamic term structure model to decompose the yield declines into changes in expectations about future monetary policy and changes in term premia. They show that the decline is due to falling term premia. Using an event-study approach, Joyce et al. (2011) report that QE1 policy has lowered medium to long rates by about a percentage point and stress the importance of the portfolio balance channel in the effectiveness of QE1. Goodhart and Ashworth (2012) argue that the effectiveness of QE1 in loosening financial conditions was larger than that of QE2 in the UK.

Note that the literature which measures the real and financial effects of UMPs in the UK does not disentangle a QE surprise from an FG surprise and only Rogers et al. (2014) employ intraday changes in yields around every MPC announcement. For instance, in another event-study approach, Joyce et al. (2011) employ survey expectations to measure QE surprises. While the methodology of Swanson (2020) allows one to measure the separate impact of FG and QE surprises on asset prices, it also produces a time series of UMP surprises where every MPC announcement is a separate observation.

The rest of this paper is organized as follows: Section 2 describes the data and the identification methodology of FG and QE surprises in the UK. Section 3 presents the analysis of important MPC announcements in the UK during the ELB period. Section 4 discusses the responses of asset prices to UMPs. Section 5 documents the persistence of the effects of FG and QE surprises on asset prices. Section 6 concludes.

3.2 Data and Methodology

The decomposition methodology employed to disentangle the effects of FG and QE on financial assets is an application of Swanson (2020). This approach provides a way to separate the relative importance of two distinct UMP tools. The Bank rate surprise, which is captured by the 30-minute change in the 1-month overnight interest swap rate (OIS1M) around each MPC meeting, is very small in absolute magnitude during the ELB period and has no significant impact on financial assets.

I follow the split sample identification in Swanson (2020). In the first step, I focus on the sample from July 1997 to February 2009, the pre-ELB period where there are two distinct monetary policy tools: the Bank rate surprise and the future path of the Bank rate communication, i.e. FG surprise. I extract the first two principal components from a matrix composed of 30-minute changes in six financial assets whose maturities range from 3 months to 10 years. Specifically, I use the 30-minute changes of the 1st, 2nd and 4th short sterling futures rates, and the 2-year, 5-year and 10-year gilt yields. The 30-minute window is between 11:50 and 12:20 on all MPC announcement days between July 1997 and February 2009. The illustration of this extraction can be represented by a factor model:

$$X = F\Lambda + \varepsilon \tag{27}$$

where X is the matrix of the high-frequency changes in financial assets, F is the matrix of principal components, Λ is the matrix of loadings and ε is a white noise residual. The dimensions of X is the number of announcements, $T = 140$, by the number of financial assets, $n = 6$. The dimensions of F is T by k, the number of principal components which is 2, and the dimensions of Λ is k by n.

As in Gürkaynak et al. (2005), I conduct the rank test of Cragg and Donald (1997) to identify the number of factors underlying the interest rate responses to the monetary policy announcements. I employ two principle components following this test. Table 13 shows that the rank test of Cragg and Donald (1997) rejects the null hypotheses that the rank of F is 0 (i.e. X is explained by a random walk) or 1 with relatively small p-values. A factor structure with two dimensions, however, sufficiently explains almost all of the variation in X matrix.

The first two principal components have no structural interpretation. However, they explain almost all of the variation in the term structure around MPC announcements. I rotate these two principal components such that the first vector moves one-to-one with the surprise change in the 1st short sterling futures rate, and the second vector captures all the variation orthogonal to the first vector by construction and corresponds to changes in interest rate expectations over subsequent horizons. Thus, the second factor has the structural interpretation of a future path of the policy rate, i.e. FG.

The rotation of these first two principal components is done by defining a 2x2 rotation matrix, U, and plugging it into the factor model given above.[57] Defining $\tilde{F} = FU$ and $\tilde{\Lambda} = U'\Lambda$, the same factor model can be rewritten as in Equation (28). This requires to make an additional (to the orthogonality assumptions implied by the rotation matrix) identifying assumption: equating the loading of the second factor that corresponds to the shortest maturity asset, the 1st sterling future, to 0. Therefore, the first column of $\tilde{F}$ has the structural interpretation of a Bank rate surprise while the second column has the future path of the policy rate interpretation.

$$X = \tilde{F}\tilde{\Lambda} + \varepsilon \tag{28}$$

This step follows from Gürkaynak et al. (2005). The second step is proposed by Swanson (2020). In this step, a similar exercise is conducted for the ELB period, from March 2009 to August 2018. Since the expectations of the short rates do not move much in the ELB period, I omit the 1st and 2nd short sterling futures from the asset matrix. Therefore, X has 4 financial assets whose maturities vary from a year to ten years.

I build the same factor model in Equation (27) for the ELB period. Table 14 shows the results of the Cragg and Donald (1997) rank test for the ELB period: the number of factors underlying the high-frequency response of the term structure around MPC announcements is 2 for this period as well.[58] The null hypotheses that the rank of the $\tilde{F}$ matrix is 0 or 1 are

[57] Since the multiplication of a rotation matrix with its transpose is the identity matrix, the equality still holds with the same residuals.

[58] I assume that the rank of $\tilde{F}$ matrix cannot exceed 2 since the Bank rate was effectively zero at the ELB.

rejected by the Cragg and Donald (1997) rank test. Thus, I extract the first two principle components of the X matrix.

The identifying assumption in this step is to minimize the Euclidean distance between the loadings of the FG factor from the pre-ELB period and the loadings of the FG factor in the ELB period. This assumption implies that the effect of the FG surprise on the term structure during the pre-ELB and ELB periods are as close as possible. Though questionable, Swanson (2020) shows that an alternative (full-sample) identification method implies a very similar FG factor. This is also true for the UK.

3.3 Analysis of Important Announcements

The resulting factors are presented in Figure 13. A negative surprise is a monetary policy easing, which corresponds to a longer than expected ELB period (FG easing) or a larger than expected asset purchase (QE easing). The vertical axis shows the standard deviation changes in the surprise factors and the horizontal axis shows the MPC announcement dates.

The blue bars in Figure 13 display the FG surprises during the ELB period. March 2009, when the first QE policy was announced and the Bank rate was reduced to its ELB, is reflected as a large tightening FG surprise. The large tightening on this day could be due to ex-ante market expectations that the MPC would buy shorter maturity gilts. Moreover, after the Brexit referendum, the markets expected an additional monetary stimulus in the July 2016 meeting while the MPC did not announce any further easing (this is reflected as a tightening larger than a standard deviation). Other FG tightenings larger than a standard deviation are the more recent announcements of September 2017, February 2018 and June 2018, in which the Bank communicated that the QE unwinding could start when the Bank rate hits 1.5% instead of 2%.

As for FG easings, the August 2009 announcement is the largest one. The term structure shifted downwards drastically as the MPC communicated a "lower path of Bank Rate than implied by market yields". Another large FG easing is the July 2013 announcement, when the MPC started to communicate the timing of the initial Bank rate hike explicitly. The third largest FG easing is the August 2016 announcement, which is the meeting after the MPC kept its policy stance following the Brexit referendum. In this meeting, the MPC cut the Bank rate by 25 basis points, signaling the extension of the ELB, along with further asset purchases. The November 2017 "Dovish Hike" and May 2018 announcements are also reflected as recent FG easing surprises larger than a standard deviation.

The pink bars in Figure 13 illustrate the QE surprises. The largest QE surprise, which is a six standard deviation easing, is the initiation of the QE policy in March 2009. The May and August 2009 announcements, when QE was expanded, also imply large QE surprises. The QE2 announcement, which involved an additional 75 billion pound asset purchases in October 2011, also corresponds to a large QE easing. Another QE easing, which is larger than 2 standard deviations, is the August 2016 announcement, when the MPC expanded QE policy after the Brexit referendum. As for QE tightenings, the only surprise larger than

2 standard deviations is the July 2009 announcement, where the MPC did not expand the QE as expected.

3.4 The Responses of Asset Prices to UMP Surprises

The effect of FG and QE surprises on asset prices during the ELB period can be estimated by an event-study approach:

$$\Delta Y_t = \beta_0 + \beta_{FG} FG_t + \beta_{QE} QE_t + \varepsilon_t \tag{29}$$

where ΔY_t is the daily change in asset prices (e.g. gilt yields, term premia, stock prices, the exchange rate).[59] Note that I did not impose β_0 to be zero but it is expected to be indistinguishable from zero since there should not be a systematic return for certain assets on announcement days due to non-monetary policy factors.

3.4.1 Response of Gilt Yields

Table 15 shows the responses of gilt yields whose maturities range from 1 year to 10 years. Each coefficient estimate shows the basis point change in gilt yields in response to a one standard deviation tightening surprise. The effect of the FG surprise on gilt yields maturing from 2 years to 6 years is statistically significant at the 1% level. The estimated effect on daily gilt yield movements is between 1 to 2 basis points for all yields. As for the QE

[59] I use log changes for stock prices and the exchange rate.

surprises, Table 15 shows that the impact of a QE surprise increases towards the long end of the term structure while it also significantly affects the medium term yields. Its effect on the 10-year gilt yield is close to 4 basis points. As expected, QE surprises affect longer term yields more while FG surprises have a larger impact on shorter term yields. FG and QE surprises, combined, explain only a third of the daily variation in medium to long-term rates.

The coefficient estimates reported in Table 15 are smaller in absolute magnitude than their US counterparts.[60] The difference in coefficient estimates could be explained by the relative importance of each monetary policy announcement in both countries. While there are 8 FOMC announcement in the US every year, there were 12 MPC announcements in the UK every year until 2018, practically the end of the sample period. Thus, while the estimated effect of a one standard deviation UMP surprise in the UK is smaller for each MPC announcement, the cumulative impact of UMP surprises is larger since there are more announcements in a given year.

The reported coefficients of determination in Table 15 are also much smaller than their US counterparts. While both UMP surprises explain up to three quarters of the daily variations of the Treasury yields on the days of FOMC announcements, they explain up to only a third of the daily variations of gilt yields in the UK. Note that both UMPs explain

[60] Swanson (2020) reports the 30-minute responses of Treasury yields to UMP surprises and finds larger coefficient estimates. Note that the daily government yield responses in both countries are slightly larger than their 30-minute responses since some announcements were followed by detailed press conferences that were outside the 30-minute intervals around monetary policy announcements. Besides, the financial markets could have taken some time to process the UMP descriptions and their economic implications.

almost all of the variation in the government yields in a 30-minute window. Thus, this stark disparity at a daily horizon could be due to other information revealed throughout the day. In fact, some important macroeconomic news, such as the quarterly inflation report,[61] are announced simultaneously with the monetary policy announcements in the UK. Moreover, unlike the US, one would expect gilt yields of the UK to be more sensitive to foreign developments revealed throughout the day as a small open economy.

It is important to note that the reported gilt yield responses are the average daily responses during the ELB period in the UK. There is an alternative line of literature which reports very large effects of LSAPs on Treasury yields (e.g. Li and Wei (2013), Vissing-Jorgensen and Krishnamurthy (2011), Gagnon et al. (2011)). The difference is mainly due to the employed sample period.[62] These studies mostly analyze the impact of LSAP surprises in late 2008 and early 2009. Extending the sample space to the whole ELB period and disentangling the impact of LSAP surprises from FG surprises yield much smaller effects.[63] Greenlaw et al. (2018) argue that the LSAP surprises had large effects on the Treasury yields at the beginning of the ELB due to severe market dislocation and illiquidity. As the markets improved, the impact of LSAP surprises on Treasury yields went

[61]The quarterly inflation report is announced simultaneously with the monetary policy announcement since 2015.

[62]These papers also employ alternative identification methods which do not use high-frequency data. For instance, Li and Wei (2013) use private holdings of Treasury securities and agency mortgage-backed securities to identify LSAP surprises.

[63]For instance, Greenlaw et al. (2018) report that extending the sample of Gagnon et al. (2011) to all FOMC announcements and controlling for the impact of FG surprises decrease the estimated impact of LSAPs on the 10-year yield from 117 basis points to 33 basis points.

down.[64] Therefore, using all monetary policy announcements implies a smaller estimated impact on government yields.

3.4.2 Response of Term Premia

I also analyze the impact of FG and QE surprises on the term premia components of gilt yields. Note that term premia are not observed data and different term structure models employ various assumptions to estimate the term premia. I use the Bank of England's term premia estimation for the UK, which is the average of several, relatively imprecise, term premia estimations implied by different term structure models. Table 16 shows that FG surprises affect the term premia component of gilt yields with maturities of 1 to 5 years. Less than half of the estimated impact of FG surprises on gilt yields at all maturities is due to the impact of FG on the term premia component of gilt yields.[65]

This result is consistent with economic theory. FG is a communication about the future path of the policy rates. Hence, it operates mostly through the expectations hypothesis of the term structure of interest rates. However, changes in expected future short rates could also affect term premia. For instance, Hanson and Stein (2015) suggest a mechanism due to investors that increase their demand for longer-term bonds following a cut in short rates. In this mechanism, the switch to riskier longer-term bonds is motivated by reaching for

[64] A parallel argument to this is the big shift in market expectations regarding the size of the announced asset purchases. For instance, QE2 is characterized as an LSAP tightening by Swanson (2020) as the size of the program did not exceed the market expectations.

[65] Note that the FG surprises in the US also have a limited impact on term premia.

higher yields. Hence, the reported coefficient estimates of FG in Table 16 are statistically significant.

The impact of QE surprises on the term premia component of gilt yields is substantial. As shown in Table 15, the effect grows with the maturity and almost two thirds of the impact on the 10-year rates are explained by the change in the term premia component of gilt yields. The mechanism through which QE surprises lower term premia is often called the portfolio balance channel. The asset purchases of the central bank reduce the bond supply in order to lower the term premia. Note that the estimated coefficients of QE surprises in Table 16 are statistically different than those in Table 15. Thus, it also moves the government yields through the signalling channel, i.e. the signalling effect of asset purchases that lowers the expected future short rates. In the US, LSAP surprises also mostly operate through the portfolio balance channel (see e.g. Gagnon et al. (2011)) while the signalling channel also exists (see e.g. Bauer and Rudebusch (2014)). Figures 14-15 summarize these findings visually, plotting the daily responses of gilt yields and their term premia at different maturities to FG and QE surprises with 95% confidence intervals.

3.4.3 Response of Stock Prices and the Exchange Rate

Table 17 shows that both the FTSE All Share (FTSE-AS) index, which captures around 600 companies traded in the London Stock Exchange, and the UK firms in the FTSE-AS index are responsive to FG surprises. A one standard deviation FG easing moves the stock prices up by 35 basis points and the volatility of the stock market down by more than a percentage point. These results are consistent with economic theory as lower interest rates would increase expected earnings and decrease the discount rate. Likewise, lower rates are expected to decrease the stock market volatility due to lower uncertainty and risk aversion as discussed in Bekaert et al. (2013).

A QE surprise does not significantly influence the stock prices and their volatility. This could be due to two opposing implications of QE surprises on macroeconomic expectations. The second chapter of this dissertation shows that, similar to a FG easing, a QE easing could be interpreted as either "good news" due to looser financial conditions (Odyssean), or "bad news" due to the central bank's revealed perception of the state of the economy (Delphic). Hence, the opposing impact of these two possible interpretations on the stock prices could be cancelling each other. On the other hand, both UMP easings significantly depreciate the British pound (ERI). The direction of this relationship is as expected due to lower international demand for UK financial securities.[66]

These results are parallel to those in the US. Swanson (2020) shows that a one standard deviation FG easing increases the S&P500 index by 25 basis points during the ELB period while the impact of an LSAP surprise is insignificant. He further shows that both UMP easings depreciate the US dollar with similar magnitudes (a one standard deviation FG surprise depreciates the dollar by 36 basis points while a one standard deviation LSAP

[66]Note that both Delphic and Odyssean interpretations of an UMP easing would depreciate the local currency due to weaker demand for local financial securities.

surprise depreciates the dollar by 19 basis points). The second chapter of this dissertation reports that an FG easing in the US during the ELB period decreases the options implied volatility of the stock market. The volatility decreasing impact of an FG easing is consistent with the findings of Bekaert et al. (2013), who find that a lax conventional monetary policy decreases the VIX, the stock market option-based implied volatility.

3.4.4 Response of Corporate Spreads and Equity Risk Premia

I also analyze the impact of UMP surprises on investment grade (IGCORPS) and high yield (HYCORPS) corporate bond spreads.[67] A UMP easing is expected to decrease corporate bond yields less than government bond yields since central banks operate their asset purchases mostly in government bond markets. Table 18 reports that a QE easing increases the corporate bond spreads (i.e. lower gilt yields faster than the corporate yields) as one would expect. Note that LSAP easings in the US also widen the corporate spreads as shown by Swanson (2020). The last column of Table 18 further shows that a QE easing very significantly increases the equity risk premia of UK firms, which is estimated by the Bank of England for the FTSE-AS and FTSE-UK indexes, by almost 4 basis points.

On the other hand, the impact of an FG surprise is not significant on IGCORPS but is marginally significant with an inverse sign on HYCOPRS. However, the opposite sign of the FG surprise is not robust to omitting outliers. Using the robust regression (rreg) option

[67] Note that the average maturity of these corporate bonds is around 8 years and the maturity of the employed risk-free rate matches the average maturity of the corporate bonds.

in Stata[68] makes the FG coefficient estimates insignificant as shown in the third and fourth columns of Table 18.[69] Dropping these outliers also makes the coefficients estimates of QE surprises significant at the 5% significance level in both regressions.

3.5 The Persistence of the Effects on Asset Prices

The persistence of the effect of FG and QE surprises on asset prices can be estimated by local projections as in Jordà (2005) with Newey and West (1987) standard errors:

$$\Delta Y_{t+h} = \beta_0 + \beta_{FG,h} FG_t + \beta_{QE,h} QE_t + \beta^h_{control} \Delta Y^m_{t-i} + \varepsilon^h_t \tag{30}$$

where ΔY_{t+h} is the change in asset prices at different monthly horizons, i.e. $Y_{t+h} - Y_{t-1}$ for $h \in \{0, 1, ..., 6\}$. FG_t and QE_t are UMP surprises. ΔY^m_{t-i}, $i \in \{1, 2, 3, 4\}$, which is the collection of preceding monthly changes of the dependent variable in the four months[70] before the announcement, is the set of control variables. The purpose of this control variable is to decrease the sampling variance of the estimator by decreasing the variance of the error term. The coefficient estimates are still consistent in the absence of these control variables since the UMP surprises, which are identified using high-frequency data, are assumed to be independent of the true past and future monetary policy shocks.

[68] The robust regression (rreg) option in Stata computes the Cook's distance for each observation after running the OLS regression and drops any observation with a Cook's distance statistic larger than 1.

[69] The identified outliers are March 2009 and August 2016 in the HYCORPS regression and March 2009 and May 2009 in the IGCORPS regression. These observations include three of the largest UMP surprises.

[70] Following Ramey (2016), and Stock and Watson (2018), I include four lags.

3.5.1 Persistence of the Responses of Gilt Yields and Term Premia

Figures 16-17 illustrate the persistence of the effects of FG and QE surprises on gilt yields with different maturities ranging from 1-year to 10-years. The impact of FG surprises on medium term yields (in particular, 1-year and 2-year yields) is significant for about three months using 95% confidence intervals. Similar to the results presented in Figure 16, Swanson (2020) reports that the impact of FG surprises on the 5-year Treasury yield persists less than a month at the 5% significance level in the US. On the other hand, Figure 17 shows that the impact of QE surprises on long term yields persists for about two months. This result is also consistent with the estimated impact of LSAP surprises in the US. Wright (2012) shows that the impact of UMPs on the long term interest rates in the first half of the ELB period persists for around two to three months.

Note that the estimated impact of QE surprises on the government yields, as shown for the UK in this paper and for the US in Wright (2012) and Swanson (2020), is relatively short lived compared to the studies that report large LSAP effects on the 10-year rates in the US (e.g. Li and Wei (2013), Vissing-Jorgensen and Krishnamurthy (2011), Gagnon et al. (2011)). These studies find that the impact on asset prices persists for at least a year. The difference between these two set of results on the persistence of the effects of LSAPs is also mainly due to employing a limited sample period as discussed above. Estimating the persistence of the effects of LSAPs on government yields using all monetary policy announcements yields much shorter lived effects.

There is a recent body of research that discusses why the effects of LSAP surprises on asset prices might be short lived. Duffie (2010) argues that large capital movements might have a transitory impact on asset prices since capital could be slow-moving and cannot be reallocated instantly due to limits on capital market intermediation in response to asset price distortions. Consistent with this argument, Fleckenstein et al. (2014) provide empirical evidence of TIPS-Treasury mispricing during the global financial crisis while Greenlaw et al. (2018) and Woodford (2012) discuss how markets reassess their reactions in response to LSAPs on the subsequent days due to the large-scale of the announced asset purchases.

In Figures 18-19, I plot the persistence of the effects of FG and QE surprises on the term premia component of gilt yields with different maturities ranging from 1-year to 10-years. The persistence of the impact of both UMPs on the term premia component of gilt yields is roughly the same as the persistence of their impact on gilt yields. While this result is especially expected for QE surprises which are shown to be mostly operating through the portfolio balance channel in the UK (see e.g. Joyce et al. (2011)), it is also consistent with the "reaching for higher yields" argument of Hanson and Stein (2015).

3.5.2 Persistence of the Responses of Stock Prices and the Pound

Next, I analyze the persistence of the impact of FG and QE surprises on stock prices, their volatility and the British pound. Figure 20 shows that the impact of FG on the FTSE All

Share index and its volatility dies out within a week, as in the US. This result is consistent with the "slow-moving capital" argument of Duffie (2010) and the "initial market overreaction" argument of Greenlaw et al. (2018).

On the other hand, the impact of FG on the British pound persists for at least six months at the 5% significance level and the size of its impact grows in absolute magnitude, up to a percentage point. Therefore, markets undervalue the induced depreciation in the British pound on the day of the MPC announcement and the pound continues to depreciate in response to the commitment of staying at the ELB for longer than expected. On the contrary, the impact of an FG surprise on the dollar is very transitory in the US.

Both the growing impact of FG on the British pound and the transitory impact of FG on the US dollar could be due to the time taken by markets to digest important news. Note that this readjustment could be in either direction. Hence, while an FG easing in the US temporarily depreciates the USD, an FG easing in the UK has a much more permanent impact on the pound. The relative overreaction of the US dollar on the day of the announcement could be explained by the relatively larger volume of transactions made in the US dollar.

The effect of QE surprises on the FTSE is insignificant at nearly all horizons. A QE easing is estimated with 95% confidence to increase the stock market index after five months. Interestingly, the impact of an LSAP surprise on stock prices in the US is also insignificant at nearly all horizons, except for a transitory impact with an expected sign after three months. These lagged responses could be explained by the gradual decrease in the uncertainty associated with the macroeconomic implications of the undertaken QE policy. The implied decrease in uncertainty could lower risk premia and the expected earnings in the financial sector could be increasing with a lag. Hence, a QE easing would be increasing stock prices with a lag of few months.[71] The response of stock market volatility over longer horizons is also consistent with this argument. A QE easing temporarily lowers stock market volatility after five months (while other policy surprises do instantaneously) due to the time it takes to process the macroeconomic implications of a QE surprise.

As in the US, the currency depreciating effect of a QE easing is very transitory. This finding is consistent with the arguments of limits on capital market intermediation and initial market overreaction as discussed above. Note that the sign of its impact on the domestic currency flips temporarily after five months. This flipped sign is also consistent with the transitory increase in stock prices after five months. If market participants observed stronger economic activity in response to QE policies, we would expect to see a lagged appreciation in the domestic currency due to higher demand for domestic financial securities.

[71] Note that this significant lagged impact is also transitory as the instantaneous effect of an FG surprise. Hence, the lagged transitory impact could also be a mispricing due to the limits on capital market intermediation as discussed by Duffie (2010).

3.6 Conclusion

Using high-frequency data, I empirically identify FG and QE surprises employed by the BoE when its policy rate was constrained by the ELB. Then, I show that both policies were effective in moving asset prices in the UK around MPC announcements. However, the UMP surprises account for up to only a third of the daily variations in gilt yields and term premia during the ELB period. Moreover, as in the US, their impact on gilt yields and term premia do not persist for more than a few months.

I further document that both FG and QE surprises significantly influence the British pound. The impact of FG persists for at least six months while the effect of QE disappears very quickly. FG surprises are also effective in moving stock prices and their volatility. However, the response of stock prices to FG surprises does not persist more than a week. I further find that corporate bond spreads and equity risk premia increase in response to QE easings.

Table 13: Testing the Number of Factors that Explain the Interest Rate Movements Around MPC Announcements in the Pre-ELB Period

No. of Factors under the Null	Degrees of Freedom	Wald Statistic	p-value
0	15	72.48	1×10^{-6}
1	9	22.62	0.07
2	4	2.49	0.65

The conducted test follows the Cragg and Donald (1997) test for the number of factors underlying the $T \times n$ matrix X of the 30-minute responses of the term structure in the UK to the MPC announcements from July 1997 to February 2009. $T = 140$ and $n = 6$. The test is for $H_0 : k = k_0$ versus $H_A : k > k_0$. Section 2 explains the methodology in detail.

Table 14: Testing the Number of Factors that Explain the Interest Rate Movements Around MPC Announcements in the ELB Period

No. of Factors under the Null	Degrees of Freedom	Wald Statistic	p-value
0	10	26.65	3×10^{-3}
1	5	9.02	0.10

The conducted test follows the Cragg and Donald (1997) test for the number of factors underlying the $T \times n$ matrix X of the 30-minute responses of the term structure in the UK to the MPC announcements from March 2009 to June 2018. $T = 105$ and $n = 4$. The test is for $H_0 : k = k_0$ versus $H_A : k > k_0$. Section 2 explains the methodology in detail.

Table 15: Response of Gilt Yields to FG and QE Surprises

	1YR	2YR	3YR	4YR	5YR	6YR	7YR	8YR	9YR	10YR
FG	0.69	1.28***	1.64***	1.70***	1.59***	1.40***	1.21**	1.04*	0.91	0.81
	(0.44)	(0.42)	(0.37)	(0.38)	(0.42)	(0.47)	(0.52)	(0.55)	(0.57)	(0.59)
QE	0.57**	1.15**	1.81***	2.42***	2.92***	3.28***	3.52***	3.68***	3.76***	3.82***
	(0.26)	(0.40)	(0.48)	(0.57)	(0.68)	(0.78)	(0.86)	(0.92)	(0.96)	(0.98)
R^2	0.15	0.22	0.28	0.32	0.34	0.34	0.35	0.35	0.35	0.35
N	105	105	105	105	105	105	105	105	105	105

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The estimated coefficients are the basis point changes in the yields in response to a standard deviation UMP surprise. The regressions are run as in Equation (29). The sample period spans the ELB period, from March 2009 to June 2018.

Table 16: Response of the Term Premia to FG and QE Surprises

	1YTP	2YTP	3YTP	4YTP	5YTP	6YTP	7YTP	8YTP	9YTP	10YTP
FG	0.26**	0.50***	0.57***	0.52***	0.39*	0.23	0.06	-0.11	-0.26	-0.39
	(0.13)	(0.12)	(0.16)	(0.19)	(0.22)	(0.26)	(0.30)	(0.35)	(0.39)	(0.44)
QE	-0.33	0.13	0.58***	0.96***	1.28***	1.56***	1.80***	2.00***	2.16***	2.29***
	(0.21)	(0.16)	(0.21)	(0.29)	(0.37)	(0.45)	(0.52)	(0.59)	(0.65)	(0.70)
R^2	0.29	0.22	0.25	0.27	0.28	0.29	0.29	0.30	0.30	0.29
N	105	105	105	105	105	105	105	105	105	105

Note: White standard errors are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The estimated coefficients are the basis point changes in the yields in response to a standard deviation UMP surprise. The regressions are run as in Equation (29). The sample period spans the ELB period, from March 2009 to June 2018.

Table 17: Responses of Stock Prices and the British Pound to FG and QE

	FTSE-AS	FTSE-UK	VFTSE	ERI
FG	-0.35***	-0.34***	1.66**	0.27***
	(0.11)	(0.08)	(0.83)	(0.07)
QE	0.09	0.09	-1.02	0.17***
	(0.15)	(0.15)	(0.79)	(0.04)
R^2	0.09	0.08	0.05	0.31
N	105	105	105	105

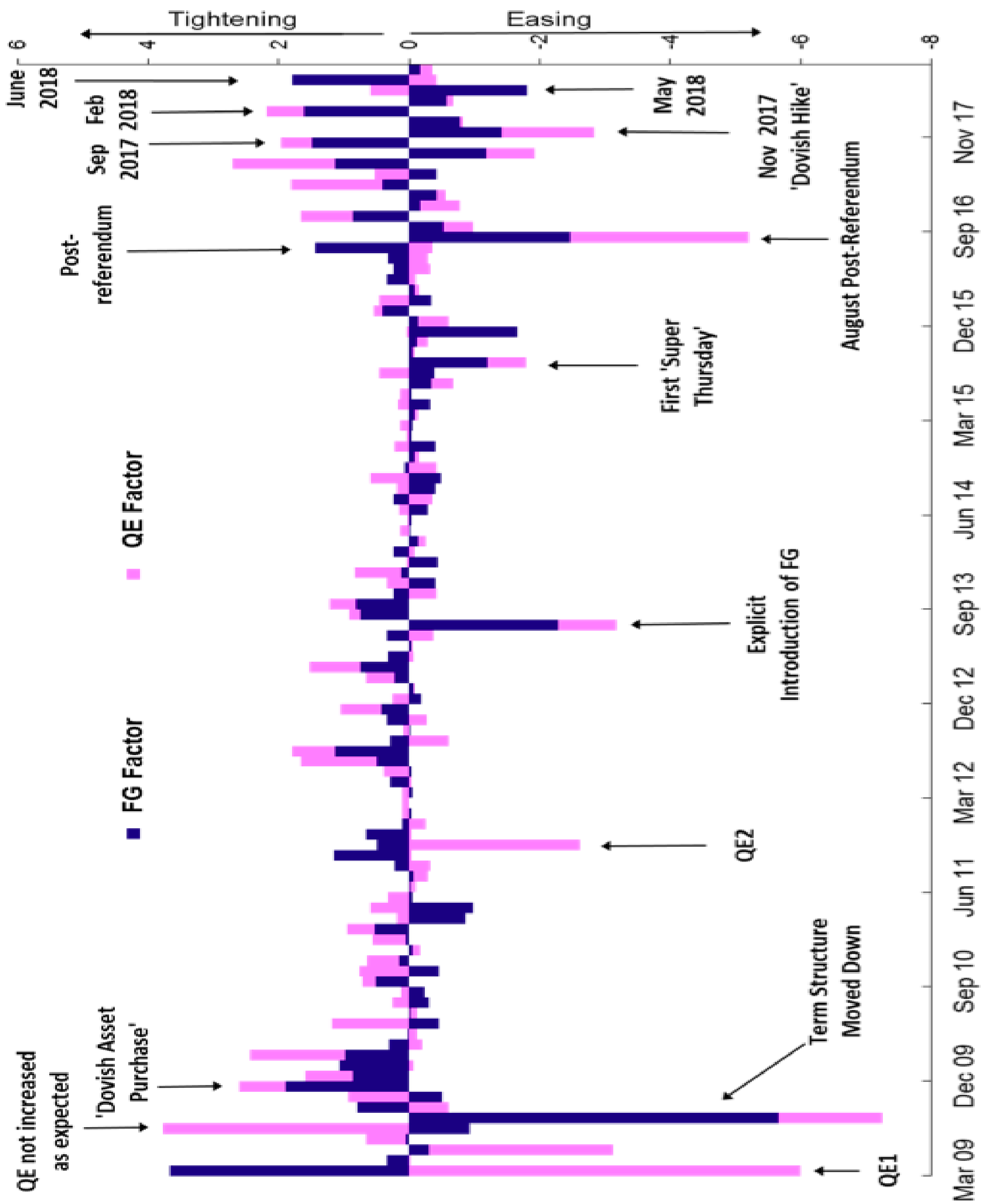
Note: White standard errors, are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The estimated coefficients are the percentage point changes in the asset prices to a standard deviation UMP surprise. The regressions are run as in Equation (29). The sample period spans the ELB period, from March 2009 to June 2018. FTSE-AS is the average stock price of all firms in the FTSE, FTSE-UK is the average stock price of all UK firms in the FTSE, VFTSE is the volatility index of the FTSE and ERI is the response of the British Pound index.

Table 18: Responses of Corporate Spreads and Equity Risk Premia to FG and QE

	IGCORPS	HYCORPS	IGCORPS	HYCORPS	ERP-AS	ERP-UK
FG	0.24	0.61*	-0.86	-0.10	0.66	0.83
	(0.12)	(0.35)	(0.63)	(0.17)	(1.16)	(0.61)
QE	-2.20	-0.94*	-1.58**	-0.39**	-2.25	-3.90***
	(1.83)	(0.48)	(0.79)	(0.20)	(1.49)	(0.95)
R^2	0.08	0.22	0.08	0.05	0.04	0.12
N	105	105	103	103	105	105

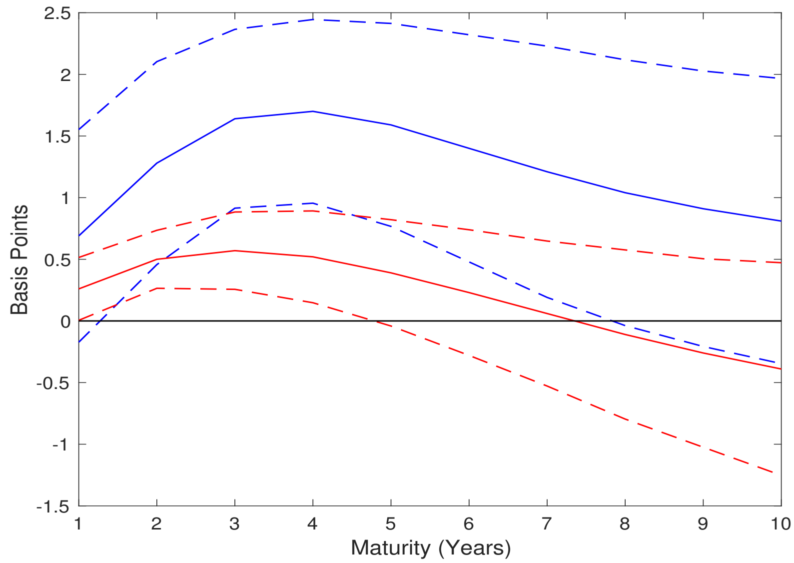
Note: White standard errors, are given in parentheses. ***, ** and * denote 1%, 5% and 10% level of significance respectively. The estimated coefficients are the basis point changes in the yields to a standard deviation UMP surprise. The regressions are run as in Equation (29). The sample period spans the ELB period, from March 2009 to June 2018. The robust regressions in the 3rd and 4th columns omit the outlier observations with Cook's distance statistic larger than 1. IGCORPS is the corporate spread of investment grade firms, HYCORPS is the corporate spread of high yield firms, ERP-AS is the equity risk premium of the FTSE-AS index and ERP-UK is the equity risk premium of the FTSE-UK index.

Figure 13: FG and QE Surprises in the UK



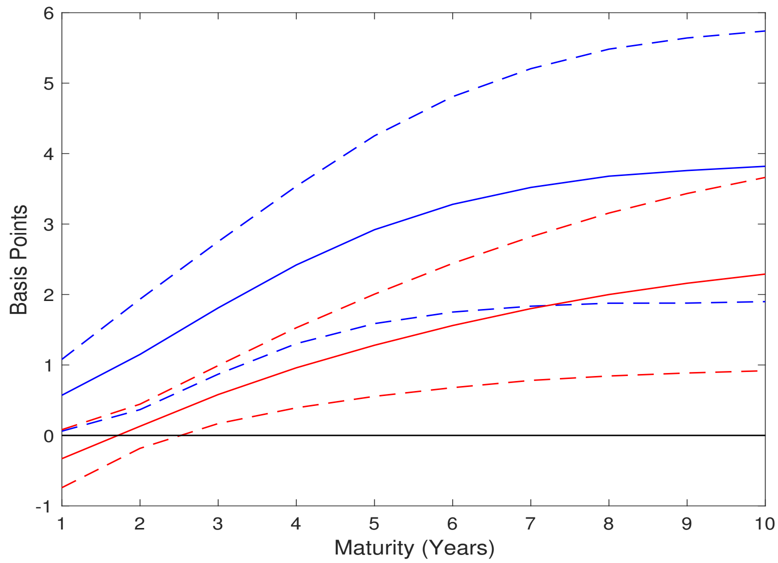
Notes: The blue bars show the FG surprise while the pink line depicts the QE surprise for each MPC announcement during the ELB period. The empirical identification methodology is as described in Section 2. Positive surprises are tightenings while negative surprises are easings. Units are in standard deviations.

Figure 14: Responses of Gilt Yields and Term Premia to FG Surprises



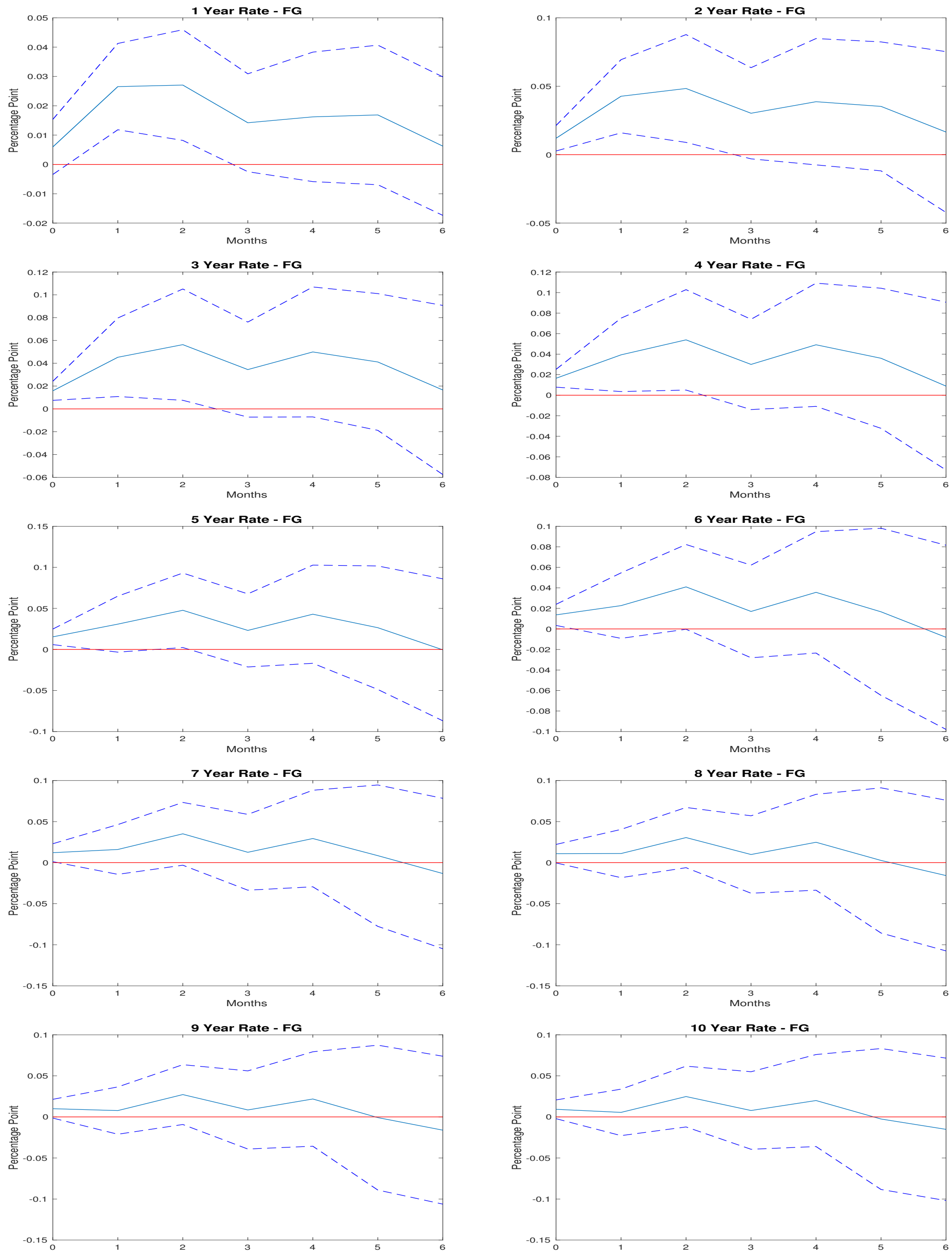
Notes: The blue solid line shows the estimated impact of FG surprises on gilt yields at different maturities while the red solid line shows the estimated impact of FG surprises on the term premia as reported in Tables 3 and 4. The dashed lines are 95% confidence bands, constructed using White standard errors.

Figure 15: Responses of Gilt Yields and Term Premia to QE Surprises



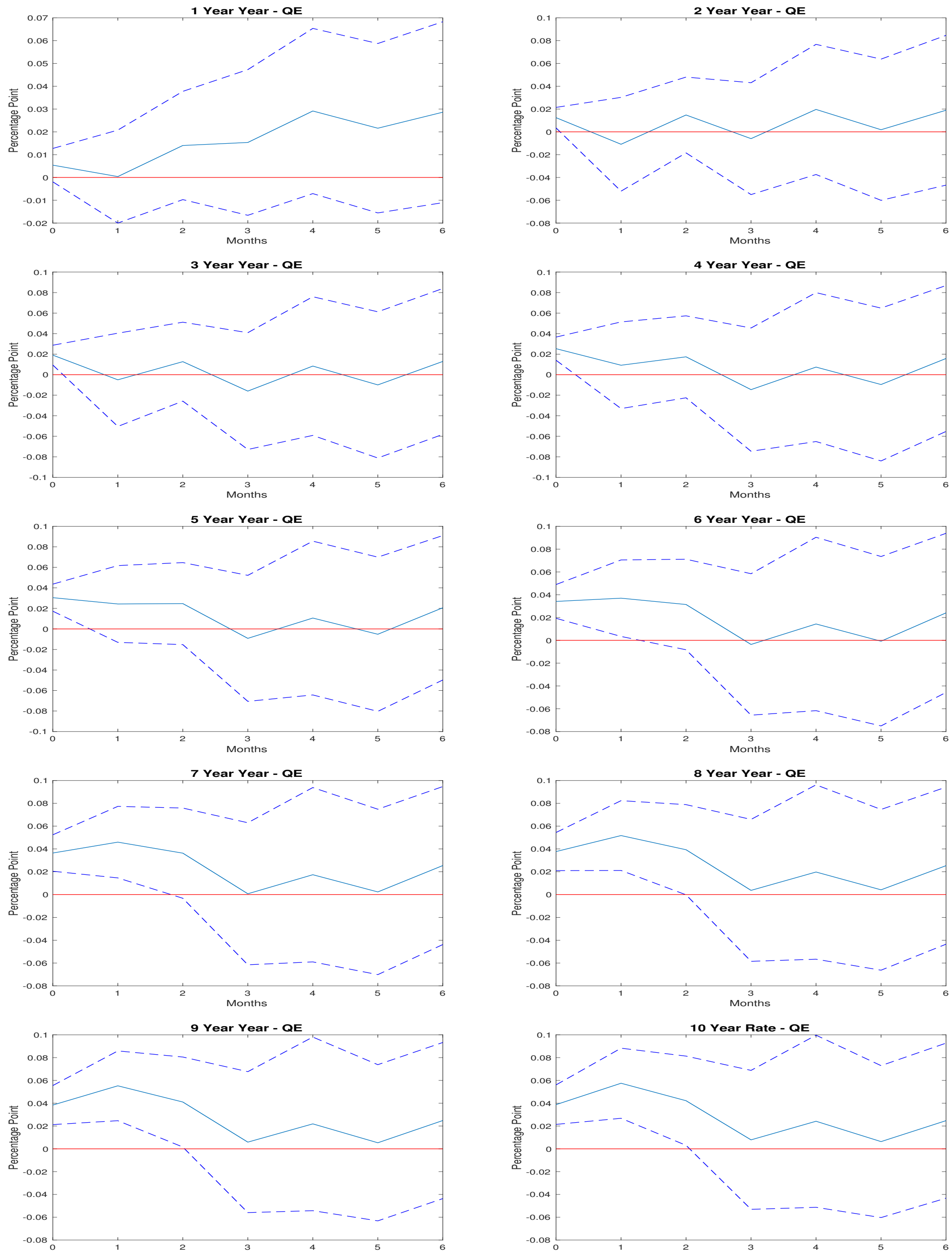
Notes: The blue solid line shows the estimated impact of QE surprises on gilt yields at different maturities while the red solid line shows the estimated impact of QE surprises on the term premia as reported in Tables 3 and 4. The dashed lines are 95% confidence bands, constructed using White standard errors.

Figure 16: Persistence of the Effect of FG on Gilt Yields



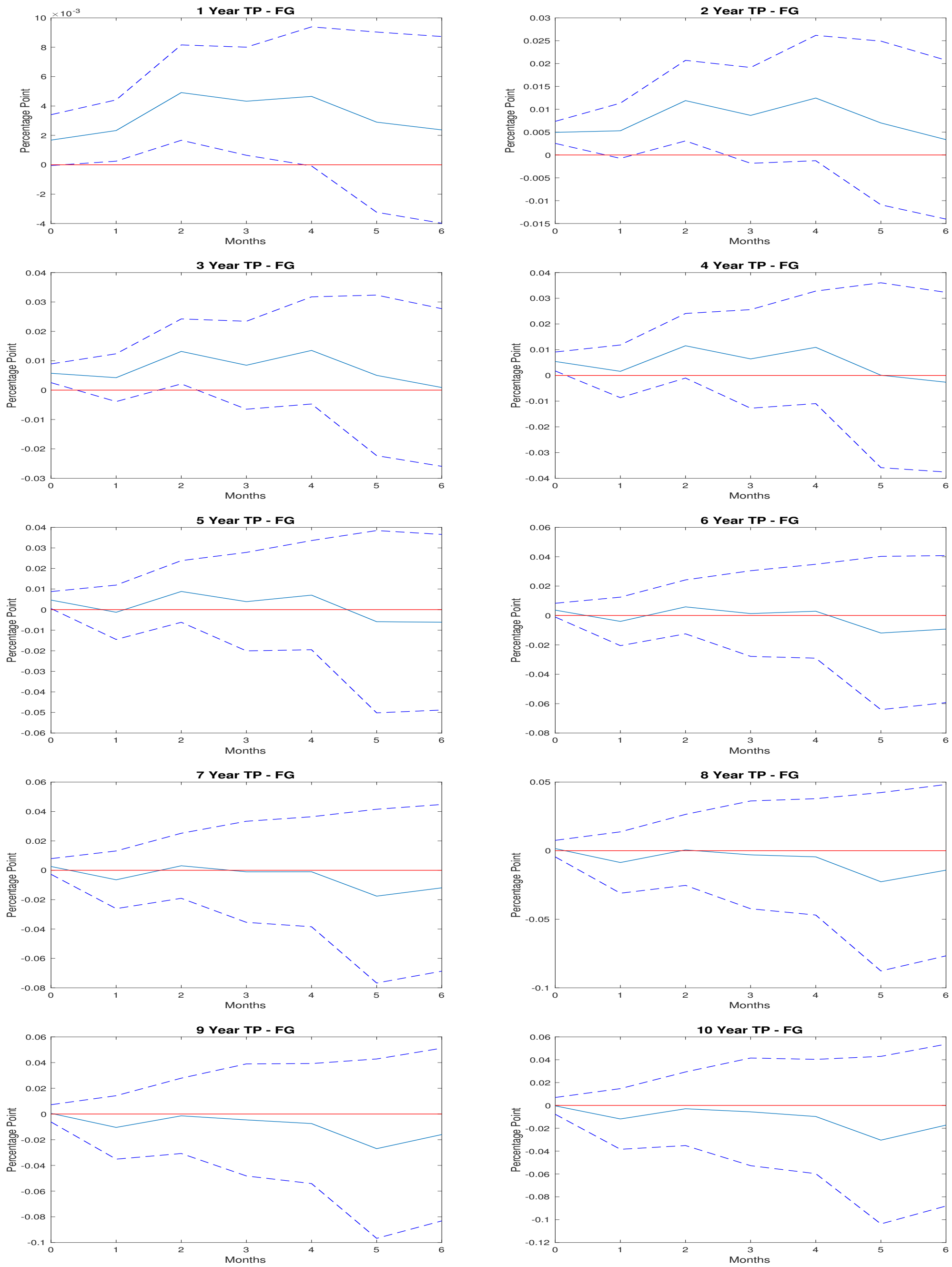
Notes: The blue solid line shows the estimated impact of an FG surprise on gilt yields with different maturities at different monthly horizons. The dashed lines are 95% confidence bands, constructed using Newey-West standard errors. The local projections are conducted as described in Section 5.

Figure 17: Persistence of the Effect of QE on Gilt Yields



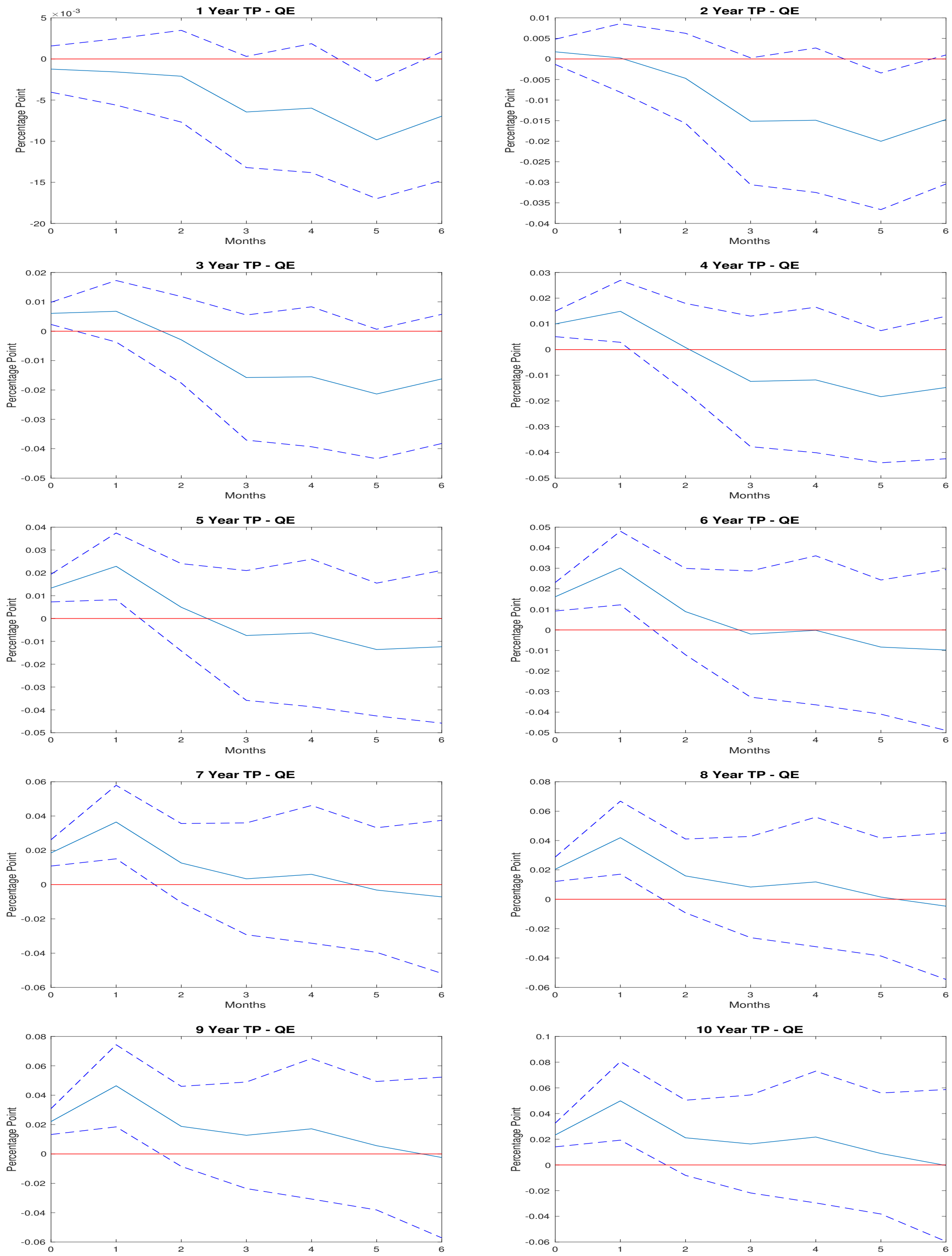
Notes: The blue solid line shows the estimated impact of a QE surprise on gilt yields with different maturities at different monthly horizons. The dashed lines are 95% confidence bands, constructed using Newey-West standard errors. The local projections are conducted as described in Section 5.

Figure 18: Persistence of the Effect of FG on the Term Premia



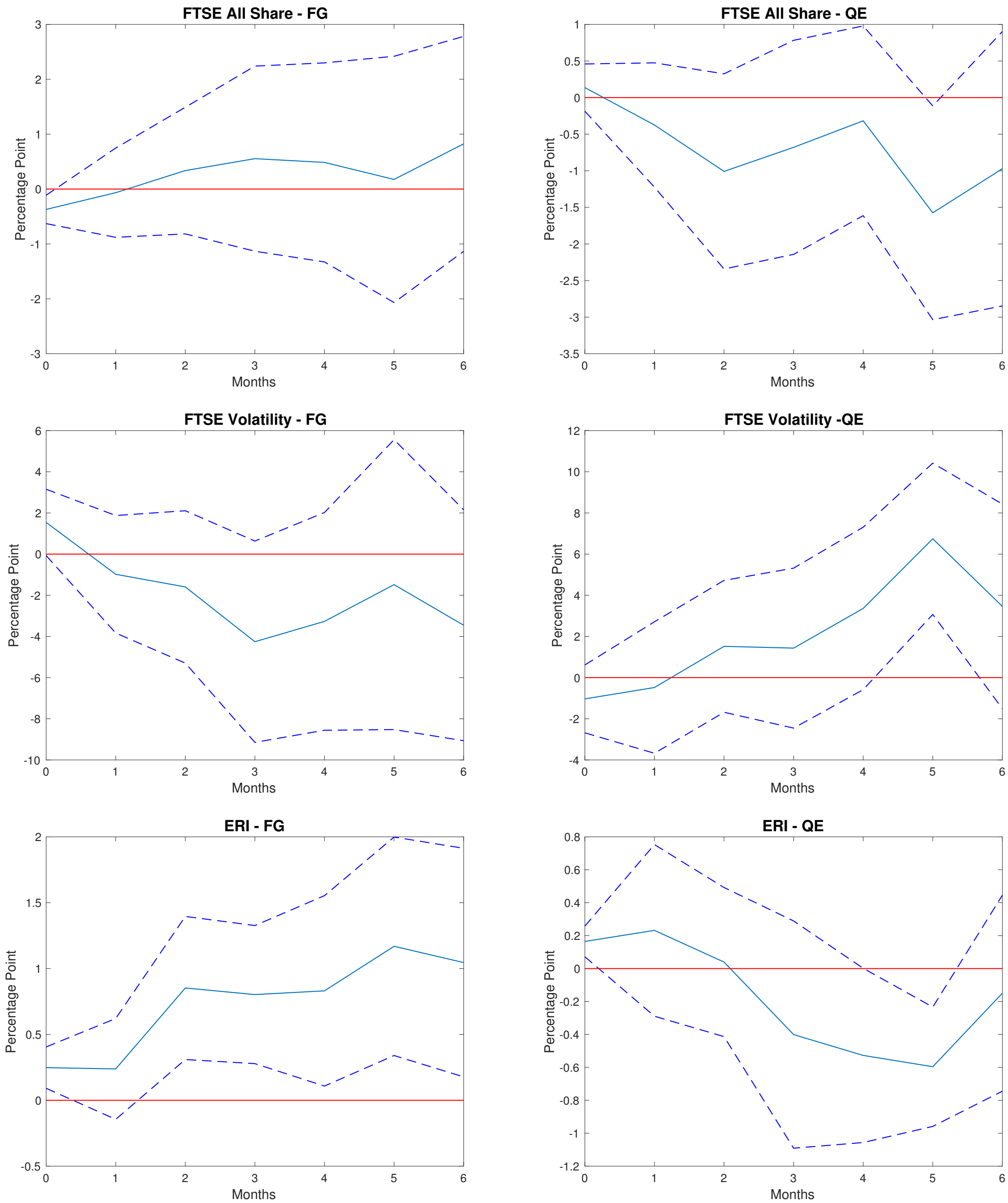
Notes: The blue solid line shows the estimated impact of an FG surprise on the term premia at different monthly horizons. The dashed lines are 95% confidence bands, constructed using Newey-West standard errors. The local projections are conducted as described in Section 5.

Figure 19: Persistence of the Effect of QE on the Term Premia



Notes: The blue solid line shows the estimated impact of a QE surprise on the term premia at different monthly horizons. The dashed lines are 95% confidence bands, constructed using Newey-West standard errors. The local projections are conducted as described in Section 5.

Figure 20: The Effect of FG and QE on Stock Prices, Market Volatility and the Pound



Notes: The blue solid line shows the estimated impact of FG and QE on stock prices, their volatility and the British Pound index (ERI) at different maturities. The dashed lines are 95% confidence bands, constructed using Newey-West standard errors. The local projections are conducted as described in Section 5.

A Appendix A: Standard Sticky Price Model

This section describes the baseline model presented in Section 3.1. The model builds on a standard sticky price model as in Gali (2008). There is staggered price setting as in Calvo (1983). The source of uncertainty in the employed model is the FG shock which changes the path of the nominal interest rate.

A.1 Households

An infinitely-lived representative household, who has access to a complete set of contingent claims, maximizes his/her expected lifetime utility subject to a standard intertemporal budget constraint and a solvency condition:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t)^{1-\sigma}}{1-\sigma} - \frac{(N_t)^{1+\varphi}}{1+\varphi} \right) \tag{A1}$$

$$\text{sbj. to } \int_0^1 P_t(i) C_t(i) di + Q_t B_t \leq B_{t-1} + W_t N_t \text{ and } \lim_{T \to \infty} \mathbb{E}_t [B_T] \geq 0 \; \forall t \tag{A2}$$

where $P_t(i)$ is the price of good i and $C_t(i)$ is the consumption of good i. B_t is the amount of one-period bonds purchased at the price of Q_t. W_t is the aggregate wage. σ denotes the CRRA and the inverse elasticity of intertemporal substitution and φ is the inverse elasticity of labor supply to wages. The variable N_t is the labor supply decision and C_t is the consumption decision. C_t can be expressed as a CES composite consumption index while N_t is a continuous sum over all firms the household works for without any imperfections in the labor market.

$$C_t = \left(\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{A3}$$

$$N_t = \int_0^1 N_t(i) di \tag{A4}$$

where ε is the elasticity of intratemporal substitution among goods.

The intertemporal choice of households implies the standard Euler equation. Therefore, the log-linearized deviation of consumption from its steady state is:

$$c_t = \mathbb{E}_t[c_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]) \tag{A5}$$

where π_t is inflation, $i_t \equiv -logQ_t$ is the deviation of the nominal interest rate from its steady state. The intratemporal choice of the household yields the standard optimality condition:

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{A6}$$

where all lower case variables are log-linearized deviations from their steady states.

A.2 Firms

All firms have a Cobb-Douglas production function: $Y_t(i) = AN_t(i)$. The production is assumed to be constant returns to scale. The technology is assumed to be constant. The aggregate output index can be defined as:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{A7}$$

The log-linearized deviations of total production and labor supply from their steady states are the same:

$$y_t = n_t \tag{A8}$$

Following Calvo (1983), $(1-\theta_p)$ fraction of the firms cannot update their prices each period. Since firms know that only θ_p fraction of the firms can update their prices each period, whenever they can update, they choose the average optimal price until the next price adjustment:

$$p_t^* = log\left(\frac{\varepsilon}{\varepsilon-1}\right) + (1-\beta(1-\theta_p)) \sum_{k=0}^{\infty} (\beta(1-\theta_p))^k \mathbb{E}_t[mc_{t+k} + p_t] \tag{A9}$$

The optimal price setting yields the standard relation between inflation and real marginal cost of production.

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda mc_t \tag{A10}$$

where $\lambda \equiv \frac{\theta_p}{(1-\theta_p)}(1-(1-\theta_p)\beta)$.

A.3 Equilibrium

With the goods market clearing condition and the consumption Euler equation, the standard dynamic IS curve (2) is obtained. Plugging the deviation of real marginal cost from its steady state in equation (A10) yields the standard NK Phillips curve (3).

B Appendix B: Adding Rigidities in the Labor Market

This is an extension to the sticky price and the sticky information models employed in this paper. First, I show that introducing wage stickiness improves the fit of the baseline sticky price model. Despite this result, I further show that the results presented in the paper are robust to introducing nominal rigidities in the labor market: a sticky price model, with or without bounded rationality (BR), cannot match the empirical impulse responses while a sticky price model with Delphic interpretation or a sticky information model can.

B.1 Sticky Price Model with Sticky Wages

The introduced nominal rigidities are as in Erceg et al. (2000). Adding monopoly power to workers in the labor market requires to redefine the labor supply index, given in Equation (A4), as a CES index with the elasticity of intratemporal substitution among labor varieties,

γ.[72]

$$N_t = \left(\int_0^1 N_t(i)^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{\gamma}{\gamma-1}} \tag{B1}$$

Besides, workers with monopoly power can choose an optimal level of wage. In the sticky price model, only θ_w fraction of them can update their wages. Consequently, one can derive the following wage inflation Phillips curve in the sticky price model as in Gali (2008):

$$\pi_t^w = \beta \, \mathbb{E}_t[\pi_{t+1}^w] + \kappa_w (\sigma + \varphi) y_t - \kappa_w (w_t - p_t) \tag{B2}$$

where $\kappa_w \equiv \frac{\theta_w}{(1-\theta_w)(1+\varphi\gamma)}(1-(1-\theta_w)\beta)$ and w_t is the deviation of the nominal wage from its steady state. Under constant returns to scale, the extended CPI inflation NKPC is derived as a function of the deviation of the real wage from its steady state.

$$\pi_t^p = \beta \, \mathbb{E}_t[\pi_{t+1}^p] + \kappa (w_t - p_t) \tag{B3}$$

The dynamic IS curve is not affected by the introduction of nominal rigidities in the labor market. Equations (2), (4), (B2) and (B3) with relevant initial conditions define the equilibrium of the sticky price model with sticky wages.

Introducing BR implies the following Phillips curves while the dynamic IS curve is as

[72]This parameter is calibrated to 6, implying a steady state wage markup of 20%.

given in Equation (6).

$$\pi_t^w = \beta \mu_w^f \mathbb{E}_t[\pi_{t+1}^w] + \kappa_w(\sigma + \varphi) y_t - \kappa_w(w_t - p_t) \tag{B4}$$

where $\mu_w^f \equiv \mu \left((1-\theta_w) + \frac{1-\beta(1-\theta_w)}{1-\beta(1-\theta_w)\mu} \theta_w \right)$.

$$\pi_t^p = \beta \mu_p^f \mathbb{E}_t[\pi_{t+1}^p] + \kappa(w_t - p_t) \tag{B5}$$

where $\mu_p^f \equiv \mu \left((1-\theta_p) + \frac{1-\beta(1-\theta_p)}{1-\beta(1-\theta_p)\mu} \theta_p \right)$.

Introducing Delphic interpretation does not change the wage and CPI inflation Phillips curves (B2)-(B3). The dynamic IS curve is as given in Equation (10).

B.2 Sticky Information Model with Labor Market Rigidities

Adding imperfections (information stickiness and monopolistic power for workers) in the labor market requires to discern a unit of household into a consumer and a worker who update their information sets at different paces in a sticky information model. θ_w parameter denotes the fraction of workers who update their information set each period. As in Reis (2009), workers solve a labor supply optimization problem while consumers solve a consumption optimization problem subject to the same budget constraint.

Given the information stickiness and the monopolistic power of workers in the labor market, the nominal wage curve can be derived as in Reis (2009). The term in expectations is the optimal wage of a worker.

$$w_t = \theta_w \sum_{i=0}^{\infty} (1-\theta_w)^i \, \mathbb{E}_{t-i} \left[p_t + \frac{\gamma(w_t - p_t)}{\gamma + \varphi} + \frac{\varphi(y_\infty - \frac{1}{\sigma}R_t)}{\frac{1}{\sigma}(\gamma + \varphi)} + \frac{n_t}{\gamma + \varphi} \right] \tag{B6}$$

where $y_\infty = \lim_{\tau \to \infty} \mathbb{E}_t(y_{t+\tau})$ is the long-run equilibrium output and $R_t = \mathbb{E}_t \sum_{\tau=0}^{\infty} (i_{t+\tau} - (p_{t+1+\tau} - p_{t+\tau}))$ is the long real interest rate. Since the optimal price is the sum of the given price level and the real marginal costs with the addition of imperfections in the labor market, the optimal price is only a function of nominal wages under constant returns to scale. The corresponding Phillips curve can be derived as in Reis (2009):

$$p_t = \theta_p \sum_{i=0}^{\infty} (1-\theta_p)^i \, \mathbb{E}_{t-i} [w_t] \tag{B7}$$

Equations (4), (17), (B6) and (B7) with relevant initial conditions define the sticky information equilibrium with imperfections in the labor market.

B.3 Matching Empirical Moments

When workers have monopolistic power in the labor market (hence, they can charge a markup in their wages) and the wages in the labor market are updated infrequently as in Calvo (1983), the overall responsiveness of macroeconomic and financial variables to an FG shock decrease drastically in a sticky price model under rational expectations (RE). Although there are few papers that employ a medium-scale NK model with wage stickiness in the FG puzzle literature (e.g. Del Negro et al. (2015)), the partial effect of wage stickiness in addressing the FG puzzle is not highlighted in the literature.

Figure B1 shows that the model-implied response of the CPI price level fits the data well while output and working hours jump implausibly at time 0 under the baseline sticky price model. The model-implied response of output gets empirically plausible more than a year after the FG shock is introduced. The initial jump in the working hours is implausibly large due to the excessive jump in output. Table B1 reports that the quadratic distance between the model-implied and empirical impulse responses, which has a χ^2 distribution, is 584 after introducing wage rigidities in the baseline sticky price model. There is still a puzzle, however the puzzle is much smaller than the one that emerges in the absence of sticky wages.

There are two reasons for the CPI level to be less responsive to the same FG shock in the presence of a wage markup and wage stickiness in the sticky price model. First, the CPI inflation is less responsive to output gap since the real marginal cost is less responsive to production (with the presence of a markup in real wages, it is relatively less responsive to the level of production). This channel outweighs the additional responsiveness of the CPI inflation created by the deviation of the real wage from its steady state in the presence of nominal rigidities in the labor market. As the CPI level deviates less from its steady state, inflation expectations are stickier and the real interest rate moves less in response to an FG shock. Given this muted path of the real interest rate, output responds less as well.

A natural question to ask after showing the better fit of a sticky price model with sticky wages is whether adding BR to a sticky price model with sticky wages can match the empirical impulse responses with an empirically plausible cognitive discount factor, μ. Table B1 shows that the cognitive discount factor that minimizes the quadratic distance between the model-implied and the empirical impulse responses is 0.23. Although introducing a sticky wage framework suffices to fit the price level, the implausible jump of output can only be muted by choosing an implausibly small cognitive discount factor, similar to the one required in the absence of sticky wages.

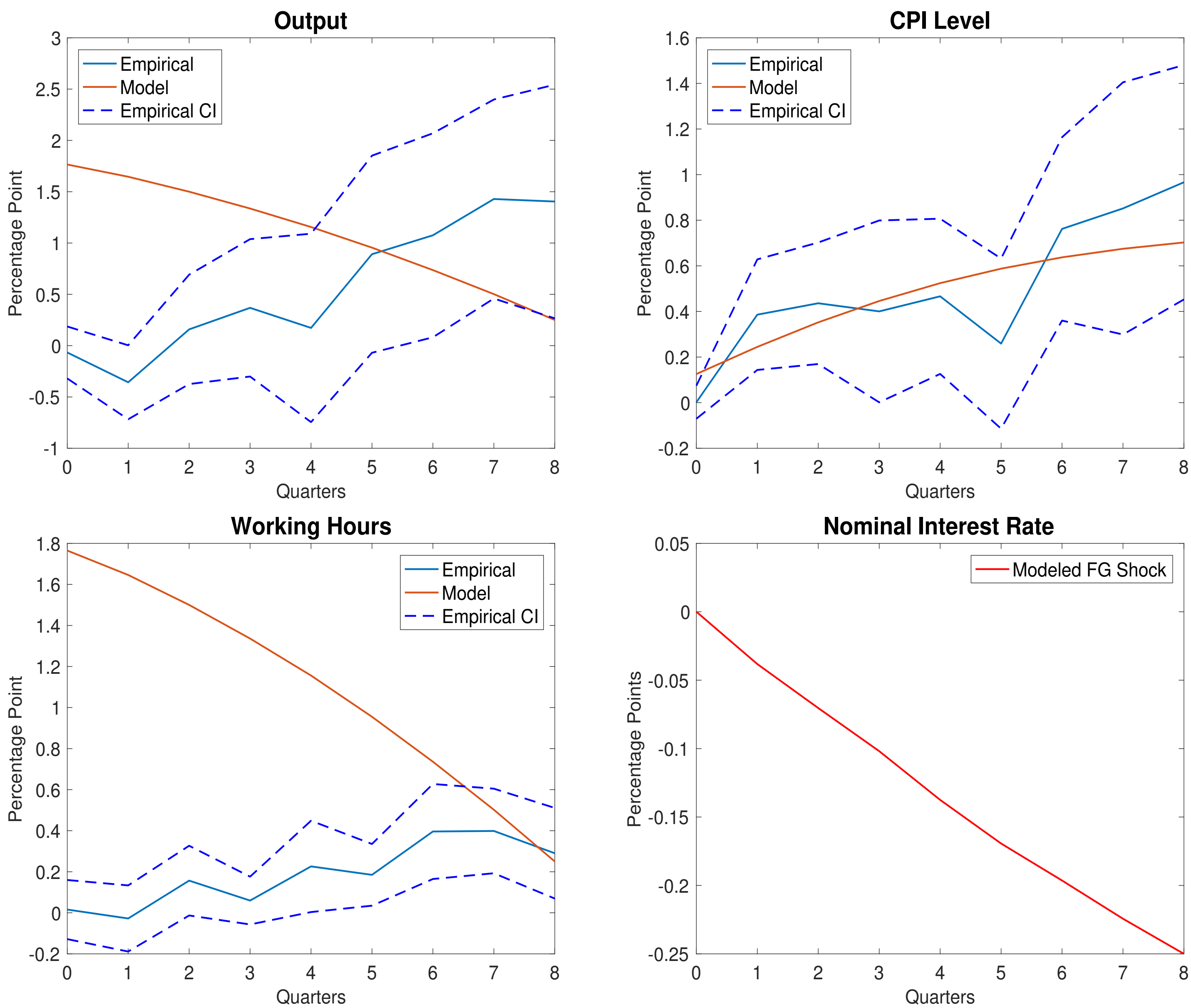
On the other hand, introducing Delphic interpretation or employing a sticky information model still addresses the puzzle in the presence of nominal rigidities in the labor market. Table B1 shows that the probability of Delphic interpretation, ψ, that best matches the data is 0.43. Likewise, when 3% of consumers update their information sets ($\delta = 0.03$), the sticky information model is able to match the data well. Although Reis (2009) estimates 3% as the lower bound of a plausible range for δ in the US, a benchmark calibration of 8% implies impulse responses that are not statistically different from their empirical counterparts at the 5% significance level.

Table B1: Estimations under Sticky Prices and Wages

	Est. Param.	χ^2	p-value
Sticky Prices and Wages	–	584	0
Sticky Prices and Wages with BR (μ)	0.23 (0.02)	24	0.55
Sticky Prices and Wages with Delphic Interp. (ψ)	0.43 (0.004)	31	0.22
Calibrated Sticky Information and Wages (δ)	0.08 –	29	0.33
Estimated Sticky Information and Wages (δ)	0.03 (0.004)	16	0.93

Note: Note that θ_w is calibrated to 0.25 in both the sticky price and the sticky information models. χ^2 test statistics are the values of the objective function in (19).

Figure B1: Baseline Sticky Price Model with Sticky Wages (Inverse Wage Stickiness = 0.25)



Notes: The model-implied impulse responses are under baseline calibration where the average duration of both prices and wages is one year, i.e. $\theta_p = \theta_w = 0.25$. The model-implied impulse responses do not have a CI since the model is fully calibrated. 68% CIs of the empirical impulse responses are constructed using Newey-West standard errors with a maximum lag of 1.5×horizon. The introduced shock is an estimated FG shock as the black line in Figure 1 of the paper.

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Vita

Derin Aksit received his BA degree in Economics from Bilkent University as valedictorian in 2015. He started his graduate studies at the Johns Hopkins University the same year. In 2017, he was awarded the Eugenio and Patricia Castillo Award by the Department of Economics for the best performance in the first two years of the PhD program. During his PhD studies, he worked as a PhD intern at the Bank of England in the summer of 2018 and as a dissertation fellow at the Federal Reserve Bank of Boston in the fall of 2020. In July 2021, he will join the Boston office of PricewaterhouseCoopers as a senior associate.